TEACHING SCIENCE

in today's secondary schools

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PREFACE

Everyone who works with prospective science teachers knows that there is never enough time in a science methods course to deal adequately with all the essentials of science teaching. It is not enough merely to tell students that demonstrations are useful teaching devices, that grouping helps care for individual differences, that science teachers have responsibilities for developing skills in mathematics. Young teachers need to know just *what* constitutes an effective demonstration, just *how* group work can be organized, just *when* to bring mathematics into the science program.

The authors of this book have not felt themselves alone in wishing for more practical helps for teachers-in-training. And so they envisioned a book that would give specific suggestions for teaching procedures. But to be really useful, such a book must do more than give practical aids, because young teachers must know *why* recommendations are made in order to use them wisely, and they need help in developing a philosophy that frees them from dependence upon others for their choice of approaches.

The authors recognize that it is difficult to predict the conditions a new teacher may encounter in his first position. He may have classes of twenty-five pupils or he may have classes of forty. He may be assigned a well-planned classroom or he may be asked to share a standard classroom with a teacher of social studies. One school system may encourage him to use field experiences, while another forbids him to take his pupils from the classroom except for fire drills. This book, therefore, tries to help the beginning teacher recognize the favorable con-

ditions that might exist. At the same time it tries to show him how to present a satisfactory program without gas or running water, how to organize group activities in a room crowded with fixed, slant-top desks, and how to improvise equipment to supplement a meager budget.

Much of the advice given the prospective teacher is necessarily conservative. A teacher who finds himself in a rigidly formal school system must adapt himself or fail. Even in the most liberal of situations a beginning teacher is usually wise to be somewhat formal in his approach until he has become acquainted with his pupils and has developed a measure of self-confidence.

However, the book continually points out the limitations as well as the strengths of formal teaching techniques, and it emphasizes the weaknesses of a program that uses no other approaches. The book stresses the contributions that are made by democratic processes in the classroom. It shows the teacher how to add gradually to his program the liberal practices that give pupils increasing responsibility for their own acts.

The book does not try to steer an inoffensive middle path between the extreme viewpoints held in science education today, but the authors insist that subject matter goals and general education goals must go hand in hand, implementing and complementing each other, neither one complete by itself. The authors cannot conceive of a science program without subject matter and they have no sympathy with those who minimize it. On the other hand they believe that the only justification for the time allotted to science is the change that is produced in the ways of thinking of young people.

The organization of the book may need a few words of explanation. The order of presentation is one that has been found especially useful when working with inexperienced teachers. The first exercises in planning are limited to such specifics as short laboratory exercises, demonstrations, brief field trips, film showings, and minor tests. After the students are acquainted with the basic techniques, they are shown how to organize these into lessons, how to organize lessons into units, and how to make units into complete programs. The remainder of the book looks ahead to the day when the teacher has developed a feeling of security and is ready to continue his professional growth.

It is unlikely that the organization of this or any other methods book can suit everyone exactly, as teaching is such an individual matter. Therefore each chapter of this book has been made independent of the others and may be used in any order with little or no cross-referencing.

Undoubtedly the philosophy of the authors is evident from the preceding paragraphs. All that remains to say is that they would like to see young people going into science teaching with a broad vision of

their profession and their responsibilities. The authors know that science teaching can be one of the most rewarding of undertakings; that with high aims the teacher always finds a challenge; and that with recognition of each small achievement as a triumph he will always find satisfaction in his work.

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TABLE OF CONTENTS

Part I: *An introduction to science teaching*

Chapter 4

THE SCIENCE PROGRAM IN OUR SCHOOLS

Part II: *The special techniques of science teaching*

Chapter 5

PUPILS SHOULD EXPERIMENT

Chapter 6

DEMONSTRATIONS OF ALL KINDS

Chapter 7

LEAVING CLASSROOM WALLS

Chapter 8

AUDIO-VISUAL AIDS IN SCIENCE TEACHING

Chapter 9

SCIENCE TEXTBOOKS, NOTEBOOKS, AND WORKBOOKS

Chapter 10

LANGUAGE AS A TEACHING AID

Chapter 11

TESTS AND TESTING

Part III: *Plans and planning*

Chapter 12

SETTING OBJECTIVES FOR SCIENCE TEACHING

Chapter 13

PLANNING SCIENCE LESSONS

Chapter 14

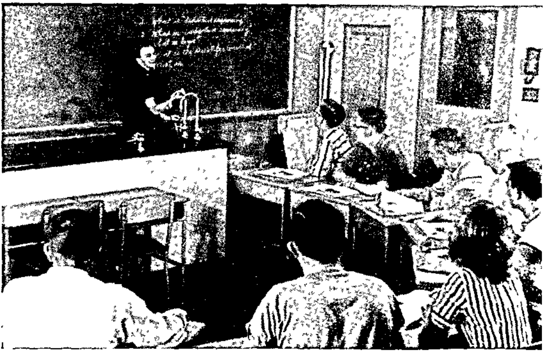
UNIT PLANNING

APPENDIX

INDEX

Part I

An introduction to science teaching



The function of the teacher is to place pupils in situations in which they can learn. The teacher should keep in the background, giving his pupils the dominant roles in the classroom. The teacher, in addition to knowing his subject matter, must know his pupils—their needs, their strengths and weaknesses, and how the science program can help them.

WHAT SCIENCE CAN DO FOR BOYS AND GIRLS

chapter 1

A classbell rings. Thirty pupils hurry from the science classroom—thirty boys and girls who soon will be taking jobs or entering college or serving in the armed forces, thirty adolescents who soon will be adults and voting citizens, thirty young people who soon will be marrying and setting up homes and having children.

What happened to these young people while they were in the classroom? Do they know a bit more about themselves? Can they now adjust more easily to new situations? Have they had increased practice in meeting problems? Are they a little better prepared for what lies ahead?

Whatever happened to these pupils depended almost entirely upon the teacher with whom they spent the hour. If he recognized the potentialities of the science program and utilized them fully, his pupils emerged from the classroom better individuals for having entered it. But if he viewed his task narrowly, or if he refused to accept his true responsibilities, the time his pupils spent with him was in all likelihood largely wasted.

Teaching is more than the presentation of facts. Teaching is the development of new ways of thinking—a development that reveals itself in increased skills with the problems of life, in new habits of action, in more desirable attitudes, in a benefited personality, and in an improved character.

A science program must be judged by its effects on individual pupils, not by the number of textbook pages read or the percentage

of a syllabus covered. Science can justify its place in the curriculum only when it produces important changes in young people—changes in their ways of thinking, in their habits of action, and in the values they assign to what they have and what they do.

Harry Cassidy, Jr., of Painted Post, New York, was selected as a finalist in the Westinghouse Annual Talent Search during his senior year in high school. During his all-expense trip to the nation's capital where he met and competed with the other finalists, he had opportunities to talk with several prominent scientists. His special project, a turbo-jet engine of his own design, attracted the attention of visiting aeronautical engineers who arranged for him a special trip to a plant manufacturing jet engines for Navy planes.

To climax the trip, Harry was declared a winner by the judges of the Talent Search. This provided him with a generous scholarship with which to further his education.

Harry has been congratulated many times for his success. Certainly he deserves the highest praise for the initiative and perseverance he displayed and his achievements should not be minimized. But looking into his background one soon realizes that credit is due also to his able and enthusiastic teacher, William Sanford of the Painted Post High School.

A turning point in Harry's life can be detected the year he met Mr. Sanford in ninth grade science. Mr. Sanford encouraged him to build a diving helmet that won a top award in a regional science fair. Then spurred on by success, and constantly encouraged by Mr. Sanford, Harry began work on a jet engine. Working after school as well as in his science classes, he gradually improved his design until he was able to build a model that astonished practicing engineers.

It is interesting to speculate as to what might have happened if Harry had not come under the influence of Mr. Sanford. Perhaps he would have discovered his potentialities under any teacher. It is probable, however, that he would not have discovered them so soon. And it is possible that with a different teacher he might have developed a life-long distaste for science.

Success stories are not uncommon in the classes of inspired science teachers. Few of these stories are as spectacular as the one just related, but the less spectacular are no less important to the individuals involved.

Bob was not a happy boy when he came into the ninth grade. He showed few strong interests. His teachers considered him lazy. He was further stigmatized by a standardized test score that classified him as almost a dullard with an IQ of 84.

But early in his general science course Bob became interested in the installation of electric circuits in a model four-room house constructed of two orange crates. Then he asked permission to install a plumbing system. Working mostly on his own time, he provided the house with running water, using a pressure tank, pipes, faucets, and a unique force pump of his own design.

Bob's interest in science and his new-found faith in his own ability continued to grow. By June he had constructed arc lamps, electric motors, an electromagnetic crane and other ingenious devices.

During his senior high school years, Bob elected both biology and physics despite the pessimism of the guidance counselor and the school administration. Among Bob's accomplishments during those years were a microprojector, an articulated fox skeleton, a split-second reaction timer, and a recording thermometer. Less tangible, but far more important, Bob developed a realistic appreciation of his own capabilities. And he convinced others, even the most skeptical, when he passed the New York State Regents examinations in biology and physics with scores of 84 percent and 92 percent respectively.

Bob's successes in science brought about complete changes in his whole pattern of behavior. He worked with greater initiative and enthusiasm in all his subjects. He was able to pass his courses and graduate from high school with a good record. He then entered a technical school to study automobile mechanics. Today he operates his own garage and is a respected person in his community.

It is certain that there are many other Harrys and Bobs in today's schools. Some of them discover their own abilities and make successes of their lives. But there must be many who do not and who are therefore a loss both to themselves and to society as a whole.

RESPONSIBILITIES OF SCIENCE IN OUR SCHOOLS

Science has added much to the world in terms of material benefits. It has also, however, complicated our lives so that people need special preparation for daily living. The secondary school science program is charged with a share of the responsibility for such preparation. In addition, secondary school science as part of the general curriculum has its obligations toward attaining the goals of the total educational program.

Responsibilities to the individual. In the United States, schools are entrusted with the task of helping every Harry and Bob, and every Susie and Kathy as well, to become all that he or she is capable of becoming. The function of our schools has been described as a seven-fold task:

1. To help each pupil fit himself into his society
2. To improve each pupil's health and personal adjustment
3. To help each pupil appraise himself realistically
4. To encourage each pupil to be independent
5. To give each pupil a broad range of exploratory experiences
6. To give each pupil skills and understandings needed for meeting the problems of everyday living
7. To prepare each pupil for the experiences of later adolescence and approaching maturity[1]

These responsibilities cannot be apportioned out one by one to the several subject matter specialists in the way that separate tasks are subcontracted during the building of a house. Social development can take place in the mathematics classroom. Young people can become aware of their environment during their art classes. A pupil can be helped with some of his personal adjustment problems by a music teacher.

Science teachers should view their obligations broadly. They should be as interested in the social development of their charges as in their academic achievement. Science teachers should be as aware of possibilities for helping young people find security as of opportunities for fostering their intellectual growth. Only thus can they help the Harrys become research engineers and the Bobs become competent mechanics. Only thus can they help each young person find his rightful place in society.

Obligations of the science program to society. American schools have a responsibility for the preservation of democracy. It is not enough to help individuals to a fuller and richer life. It is essential that individuals be able to contribute to the maintenance of the society in which they live.

The science program of the secondary schools has a role in the perpetuation of democracy. Our increasing population and the development of machines have intensified many problems of public health and safety. The same factors are causing a serious depletion in the supply of natural resources. The public needs knowledge—knowledge that will help reduce the spread of disease and the toll of accidents, knowledge that enables people to take better care of their possessions and reduce waste.

As new scientific advances are made, people need basic understandings to help interpret the significance of these advances. Education cannot stop short with graduation but must continue through each individual's lifetime. The foundation for this education must be laid in the

[1] Adapted from "A Design for Early Secondary School Education in New York State," New York State Education Department, Albany, N. Y., 1955.

public schools with the science program taking a large share of the responsibility.

If a society based on science and technology is not to stagnate, there must be continued contributions of new knowledge. Many people are needed to do basic scientific research. Others are needed to do technological research. And many more are needed to put new discoveries into useful form. There must be constant recruitment of personnel for scientific occupations. Here again, the secondary school science program has a key role.

Lastly, a democratic society needs an enlightened people who reason clearly, who respect others, and who understand justice. These traits are typical of the true scientist, with his reluctance to jump to conclusions, his habit of weighing evidence, his tolerance and his open-mindedness. The development of the scientific way of thinking in every young person is a solemn obligation of our schools.

CONTRIBUTIONS OF THE SCIENCE PROGRAM

In imagination let us visit the classroom of a master teacher who has a vision of what science can do for boys and girls.

Mr. Bayles has introduced a unit on the study of digestion to his eighth grade science class. There have been discussions, text book assignments, and a few demonstrations. Today, the class is broken up into small groups each of which is working on a special problem.

Two girls have spread a sheet of chart paper on a large table and are now sketching in the outlines of a diagram of the human digestive system as presented in a biology book. They plan to color the organs and attach suitable labels.

Three girls and a boy who have tentative interests in nursing and medicine respectively have volunteered to dissect the digestive system of a white rat. Mr. Bayles has already killed and skinned the rat. Now the pupils are studying a zoology manual to find out where to begin the incisions.

Four groups of three pupils each are setting up simple experiments which they will later present to the class as a whole. One group is testing the effect of saliva on starch. Another group is testing the effect of artificial gastric juice on the white of a boiled egg. A third group is testing the effect of a commercial preparation of a pancreatic enzyme on starch. The fourth group is showing the emulsification of fats.

In the reading center of the room four boys are looking in physiology textbooks for the names and functions of the several digestive enzymes. They plan to prepare a chart summarizing the information.

Two girls are planning a research project on conditions that affect the acidity of saliva. With litmus paper as an indicator, they intend to test the

saliva of individuals before and after eating and drinking various foods and beverages. They hope the final project will be worthy of entry in a science fair

In a far corner of the room, at a workbench, three boys are building an electric chart that will light up when the correct answers to questions on digestion have been selected. Two of the boys are drilling the needed holes in a sheet of plyboard. The third boy is cutting lengths of wire.

Some questions immediately come to mind. What are the outcomes of a science period conducted in this fashion? Are the pupils learning basic science? Are there disadvantages in having different outcomes for different pupils? What would a pencil-and-paper test reveal at the end of the period? What other types of evaluation procedures should be applied to determine the effectiveness of the lesson?

Before analyzing the lesson the nature of the pupils must be considered. Each pupil is an individual. Each has his own characteristics —his own abilities, interests, and background. Although Mr. Bayles may be said to have an average group, he has no average pupils. Even if he wished for uniform outcomes he could not possibly attain them. Outcomes will vary with each pupil.

Some of the pupils are doing work that is the academic equivalent of senior high school biology. There should be no surprise in this. In any unselected junior high school group there are likely to be several individuals of high academic ability. Such pupils need only encouragement to work up to capacity.

At the other extreme there are pupils doing manipulative work that does not seem up to eighth grade standards. This should be no matter for surprise. In any unselected group there are apt to be pupils who do not work up to their academic norm. If assigned work is beyond their abilities, or lies outside their feeling of competence, they either fail or refuse to try, and do not benefit in any manner. But if they are assigned tasks within their known abilities, they not only succeed but also make important contributions to the work of the class as a whole.

The majority of the class are working on tasks more typical of eighth grade pupils. At the moment they certainly are not all learning the same facts. But assuming that Mr. Bayles will provide opportunities for the sharing of information it is probable that all will emerge with a common core of learnings; even the academically retarded pupils will have benefited by the oral reports and excellent visual aids produced.

Mr. Bayles' classroom represents a type of situation that pupils like. They like activity. They like the excitement and the suspense of experiments. They like working together. They like permissive assignments.

The problem of providing an interesting program is not one to be passed over lightly. Pupils have many decisions to make before reaching full maturity. They may elect advanced science courses if their general science courses have been challenging; they are not apt to continue with science if they found their beginning courses dull. They may choose to enter scientific vocations if they have found that they like science class work; they are apt to shun this field if they found science distasteful.

Mr. Bayles' pupils are engaged in problem solving. As they work they encounter countless minor problems that call for analysis and ingenuity. These problems are similar to the problems they will encounter all during their lives. They are learning to solve them through experimentation, deduction, reference to books, and study of analogous situations.

Each of Mr. Bayles' pupils has opportunities to explore his own potentialities. As he succeeds he gains confidence in himself. When he fails he notes his limitations but is not defeated by them because he knows that there are other areas in which he has competence.

Each pupil finds satisfaction in his work. Each one recognizes his ability to carry out his specific assignments. No one is held back and subjected to boredom. No one is forced into competition that can only result in failure.

Pupils working together under these conditions develop a healthy respect for each other. The class has no dividing line between successes and failures but is made up of different individuals with different kinds of abilities. The academically brilliant pupil finds reason to admire the achievements of pupils with other gifts. Academically retarded pupils, now secure in their own successes, lose their envy of more fortunate classmates.

Mr. Bayles' classroom is able to make contributions to the social development of his charges. Boys and girls need practice with social skills as well as information about them. In the group work which Mr. Bayles has organized, pupils have opportunities to plan together, to present opinions and to listen to the opinions of others, to accept and to compromise, to allot and to accept responsibilities, to exert leadership, and to adjust themselves to others.

Countless minor contributions can be anticipated from Mr. Bayles' lesson. The pupils dissecting the white rat are experiencing something of what they must expect if they train for medical fields. The girls making the chart are learning to present information in graphic form. The boys using the physiology books are gaining practice with indexes and glossaries. The boys making the electric chart are developing skills with tools. The girls studying the pH of saliva are using some of

the techniques of scientific research. The list stretches on endlessly.

It cannot be assumed that this one lesson will produce sensational permanent changes in individual pupils. It is the impact of this type of teaching day after day and year after year that slowly shapes pupils into the product our schools are commissioned to put out.

Types of outcomes of the science program. The analysis of Mr. Bayles' lesson shows that many different outcomes may be expected from a properly planned and conducted science program. These may be classified under four headings.

First, there are the *subject matter learnings*. Many of these may be considered essential for a full and happy life today. All science learnings serve as "the foundation of understanding, the material with which habits of thinking and attitudes are built, the substances from which principles are induced." [2]

Second are the outcomes that may be classed as *skills*. Some of these are manipulative skills such as those used in working with tools. Some are technical skills, such as the knowledge of how to use scientific apparatus. Some are academic skills, such as those used in working with dictionaries, handbooks, and tables and in writing reports. Some are general, and include leadership skills and skills in problem solving.

Thirdly, come the *habits of thinking* that may be developed through work in the science program. Among these are the habits of looking for cause and effect relationships, of using care in making observations, and of looking to authority for the answers to questions. Included also are habits of self-reliance and habits of using all the senses.

Lastly come the *attitudes*. These range widely. A liking for scientific work and a dislike for sensational advertising may be given as examples of "positive and negative" attitudes. A critical attitude towards unsubstantiated statements, a tolerant attitude towards other people, and open-mindedness are other attitudes that may emerge from participation in science classes.

The function of subject matter. "The trend is definitely in the direction of using science content as a means to an end of better adjustment rather than as an end in itself." [3] Throughout the last few decades there has been an increasing recognition of the dual function of science subject matter. Subject matter has value not only for itself but also for the beneficial changes that can be produced in young people as they deal with it.

[2] Miller, D. E., and Blaydes, G. W., *Methods and Materials for Teaching Biological Sciences*, McGraw-Hill, New York, 1938.

[3] Heiss, E. D., Obourn, E. S., and Hoffman, M. A., *Modern Science Teaching*, Macmillan, New York, 1950.

There is always danger that the subject matter specialist will fail to recognize this second function of the material he includes in his science course. He may have forgotten, if he ever realized, the part that subject matter played in his own development. He may assume that by exposing pupils to a certain amount of information, by taking them through a predetermined number of exercises, or by drilling them upon an arbitrary number of principles, he is meeting the goals of science education.

The true teacher has full respect for subject matter. He knows that it is subject matter that pupils are studying when they set up demonstrations, when they plan group work, when they build models, and when they read books. He knows that without subject matter there can be no science program.

He knows, however, that subject matter may be as important for the changes it produces in young people as for its own sake. So he selects the content of his course in terms of what it will do for his pupils. He then puts the subject matter to work, using all the techniques at his disposal to achieve the broad goals of the science program.

The function of the teacher. It may be said that the task of a teacher is not so much to teach as to place pupils in situations in which they can learn. Learning, whether in the narrow informational sense, or in the broader sense of understanding, is largely an internal process. Pupils themselves must recognize problems. They must plan their own methods of attack. They must reason out their own conclusions.

The teacher who thinks of himself as a reservoir of information may stifle rather than stimulate his pupils. The mere presentation of facts, one after the other, will initiate very little mental activity. The answer to a pupil's question, given without any effort to challenge him further, may bring an end to his thinking along that particular line.

A teacher should think of himself as a source book—a source book of problems that challenge pupils, a source book of suggestions for field work and of laboratory activities and projects that pupils may use in solving problems, and a source book of references to films, slides and supplementary science books where pupils can find ways to solve their problems. Only by being such a source of ideas can the teacher begin to attain the goals of science education.

ATTRIBUTES OF THE SCIENCE PROGRAM

Science makes its contributions to young people in a dual role. As part of the general curriculum it works towards the general goals of education by using many of the same procedures as are used in other sub-

ject matter areas. As a special subject it works towards its goals with its own procedures. The outcomes, however, cannot be distinguished and no attempt should be made to separate them. The ultimate objective is always the same—to help each person become all that he is capable of becoming.

Broadened interests. Trees and stars and magnets and rust and a thousand other topics make up the science program. At every turning there are opportunities to strengthen early interests and form new ones.

Under suitable conditions these strong science interests lead pupils into many types of fruitful pursuits. One finds young people working long hours in school laboratories to solve special problems. One finds others spending long hours in libraries following up new leads. One finds still others employing their evenings at home working on models or collections.

Such strong interests can color the lives of young people for many years to come. They make school an exciting place and they enable science to compete favorably with athletics and social functions. The interest often spreads from science to other subjects, especially if teachers know how to capitalize on these interests, and thus make the entire educational program more exciting to young people.

Strong interests, when given proper recognition, change the individual's viewpoint of himself. He becomes more self-sufficient. He finds that others are impressed by his energy and enthusiasm, and his respect for himself increases.

Strong interests improve a young person's social adjustment. He ceases to pose. He becomes a better conversationalist, losing self-consciousness in his enthusiasms. His enthusiasm is often contagious and he learns the power of persuasion.

Strong interests, of course, help determine decisions about future occupations. Many a scientist has entered his career because of the influence of a high school science teacher or because he encountered a science topic of special appeal while still at an early age.

The development of strong science interests is necessarily one of the major goals of the secondary school science program. Strong interests cannot be expected to arise spontaneously; they must be planted and nourished. They flourish best in a classroom where pupils are treated as individuals and where they are given opportunities to explore and experiment. They are rarely developed in the classroom where mass instruction techniques and lock-step procedures prevail.

An enriched background of experiences. Learning may be likened to rolling a snowball, which, as it grows, presents an ever-increasing surface for the accumulation of more snow. Or it may be likened to a

nuclear chain reaction in which the fission of one nucleus releases several neutrons that produce fission in several other nuclei. Learning is an ever-expanding process; each new experience gives meaning to additional experiences. The educated person is he whose experiences began early and continued at a rapid rate.

Young people meet up with many different things and situations out of school, but these encounters may not always represent meaningful experiences. A person may look at a table top without seeing the grain or hear a bird sing without listening to the pattern of its notes. Experiences must be related to knowledge before they have significance.

The science program, which deals with so many things in the environment, not only provides meaningful experiences within the classroom, but by so doing it can change the casual contacts of everyday life into additional meaningful experiences.

Experiences in the science program are not limited to the things of science. As pupils work together in the varied activities of a good program they encounter social experiences as well. A teacher with a broad concept of his responsibilities recognizes the value of social experiences and provides for them.

To take maximum advantage of the interaction of in-school and out-of-school experiences, the well-planned science program has a carefully considered sequence. Early experiences deal chiefly with things and situations the pupils encounter daily. Later experiences can then be built upon a base of integrated in-school and out-of-school experiences. These later experiences are planned to give, in their turn, meaning to additional out-of-school experiences. And thus the background of the pupils grows.

Important subject matter learnings. Pupils emerge from the well-planned and well-taught science program with much needed information about the care of their own bodies. They have learned about nutrition and reaction times and disease. They understand how to apply the principles of mechanics and electricity to prevent accidents. They recognize the contributions of public health measures and understand their obligations in this area.

Through their study of themselves they have gained a knowledge of sex and its implications. They have developed a vocabulary suitable for discussing this topic with their doctors. They recognize the changes taking place in their bodies as natural and nothing to cause shame or fear.

Pupils will have gained information about soaps and deodorants, about posture and balance, about color harmonies and dress. They will have learned how to take care of the details of personal grooming and

themselves. They can use trial-and-error procedures, the inductive method, the deductive method, and all other methods of attack.

From their work in science pupils should learn to look for cause and effect relationships. They should develop the habits of deferring judgment, of weighing evidence, and drawing tentative conclusions. They should become critical of unsupported statements but at the same time learn to be tolerant of the opinions of others. They should wish to test all conclusions and they should be willing to change their opinions when new evidence is presented.

These habits and attitudes, so closely allied to science, have equal significance in all other aspects of life. If pupils will apply them to the decisions that inevitably face them in their later lives—voting, buying, even driving automobiles, their lives will be much improved and society will be greatly benefited.

Personality development. Adolescence is a critical period in the development of personality. The ways of childhood have been discarded and young people are groping towards maturity. They are particularly sensitive to the many influences, both good and bad, that act upon them.

Subject matter specialists have been inclined to shrug aside any consideration of this aspect of pupil growth, believing it to lie outside their realm. And yet incidentally, without deliberate planning, subject matter specialists often bring about complete reversals in personality, producing from neutral or negative individuals persons who are dynamic and productive. Many a successful person in the world today can point to some subject matter specialist who changed his entire life.

On the other side of the picture, subject matter specialists have without thinking harmed many young people either by refusing them opportunities to develop fully or by convincing them that they are hopeless failures. Pupils who believe they lack all potential either sink into apathy or turn to other activities, sometimes crime, for satisfaction.

The problem of personality development is not confined to the pupils who are often classed as "dull." Many a truly brilliant youngster drifts through his secondary school years never realizing his real abilities. He does well enough in his mass-instruction courses but feels no special challenge. As he drifts he develops habits that can be detrimental to later success.

The science program provides an ideal setting for the development of personality. Its range of content is broad and there is material that appeals to any interest. It calls for the exercise of many varied skills and abilities. The teacher need not be concerned with "brilliant" and "dull" students but only with young people of many different talents.

In the science program there is a place for the pupil who has superior academic ability; he can find unlimited challenge in the work and use all his skills in the solution of problems. The following list of papers submitted in a national science contest sponsored by the American Society of Metals in 1956 gives an idea of the amazing heights to which secondary pupils can be encouraged to go:

The Mathematical Relations among the Axes and Axial Angles of Metallic Crystals
Effect of Quenching Media of Steels
A Bismuth Resistance Thermometer
Applications of Advanced Mathematics to Crystallography
Crystal Habit and Growth
The Cadmium Sulfide Solar Battery
Study of Decalescence and Recalescence Zones in Steel
Chemical Corrosion of Titanium and Aluminum
Metallurgical Studies of Mn-Zn Ferrites
Selective Etching of Iron and Nickel
Factors Affecting Depth of Case of Carburizing
An Attempt to Identify the Constituents of Common Alloys by Paper Chromotography [4]

There is an equally important place for pupils with highly developed manipulative skills. Some of the most interesting exhibits at science shows are the models and other devices produced by pupils of inferior academic ability. These projects represent excellent learning activities in themselves and as visual aids they benefit the classmates of their makers.

Artistic skills too find employment. As pupils prepare charts, models, and dioramas, and carry out a multitude of other possible projects, they have opportunities to practice artistic skills and obtain high satisfaction in their achievements. The recognition these pupils receive for their work contributes much to their feeling of security.

As pupils become engaged in the numerous activities open to them, they learn much about themselves. Sometimes they succeed, sometimes they fail. They need the successes to discover their strengths. They need the failures to discover their limitations.

Success gives the pupils needed self-confidence and the desire to continue. Once a pupil has assured himself that he has worthwhile abilities he is willing to look at himself more honestly. He may regret his limitations but he is not defeated by them. Sometimes, as his confidence grows, he makes deliberate efforts to remedy weaknesses or to compensate for them.

[4] "1956 Winners, Science Achievement Awards for Students," *The Science Teacher*, May, 1956.

Occasional failures do pupils no harm unless they are exposed to condemnation and ridicule. Inability to make a bend in glass tubing, mistakes on a test, lack of skill with a saw—these merely point out to pupils what they cannot do well. It is only continued failure that makes an individual lose confidence in himself and wish to flee from the situation in which he is experiencing his failures.

Suggested activities

1. List the reasons why you believe science should be a part of the secondary school program. Then discuss your list with other prospective teachers and modify it as your ideas change. Save the list and reconsider it at the end of your methods course.
2. Observe a science class and make a record of all the teacher planned activities (i.e., experiments, demonstrations, projects) in which the pupils are engaged. Try to determine the beneficial outcomes of each activity. Note also the situations which do not seem to produce beneficial outcomes.
3. Many science teachers claim that their main job is to teach facts. Debate this point with other prospective science teachers.
4. What do you think is the function of the teacher in a science classroom? Organize a panel discussion on this topic.

Suggested readings

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THE PUPILS WE TEACH

chapter 2

Each autumn the science teacher is confronted by a group of new faces. Some of these pupils stand out almost from the beginning; others are more retiring. But eventually the teacher becomes acquainted with all of them.

One thing is obvious immediately. A class is not a uniform structure nor is it made up of stereotyped personalities. Each pupil is an individual with his own interests and abilities and experiences. The fact that a few pupils seem to merge into a characterless pattern is due to a lack of close acquaintance; true familiarity would quickly separate them into distinct personalities.

Another point becomes obvious as the year progresses. There are no convenient labels by which the pupils may be classified. One pupil may be superior in reading ability but inept with tools. A second pupil may be well coordinated physically but badly adjusted emotionally. A third pupil may be low in general academic ability but may still be a joy to work with because of his interest, enthusiasm, and willingness. *Each pupil has special strengths and limitations. None can be considered as "average," "above average," and "below average."*

A third characteristic reveals itself more slowly but with equal insistence. *The pupils are constantly in a state of change.* Their bodies change. Their ways of thinking change. Their personalities change. By the time the school year ends only the names have remained unchanged.

All this variation and change should be gratifying. The world needs

people of different talents and interests, progress would be impossible if all individuals were the same. The world has a place for each special type of ability. The science teacher's major responsibility is the nurturing of each specific talent to the utmost, taking each pupil from where he finds him, never trying to mold all pupils into the same pattern.

RANGE OF PUPILS IN GENERAL SCIENCE

The years of the early secondary school are the years in which pupils vary the most. These are also the years when most pupils are required to study general science. In consequence, the teaching of general science has special problems that are not shared with the teaching of the elective sciences in the senior high school.

The age range. Because few children enter the first grade before the age of six, most seventh grade pupils are twelve years old or older. Table 1 shows the age range in the early secondary school years. The younger pupils have had an early start or have been allowed to skip grades. The older pupils have started later, or lost time because of sickness, or were compelled to repeat grades.

Chronological Age	*Number of pupils of various ages* Grade 7	Grade 8	Grade 9	Total
17-0 to 17-5	0	0	1	1
16-6 to 16-11	0	3	9	12
16-0 to 16-5	1	4	17	22
15-6 to 15-11	1	6	34	41
15-0 to 15-5	3	14	34	51
14-6 to 14-11	8	34	61	103
14-0 to 14-5	8	43	101	152
13-6 to 13-11	23	60	51	134
13-0 to 13-5	18	78	10	106
12-6 to 12-11	61	35	1	97
12-0 to 12-5	51	1	1	53
11-6 to 11-11	13	1	0	14
11-0 to 11-5	6	0	0	6

TABLE 1. *A distribution of the chronological ages of pupils from grades 7 through 9 in a junior high school.* (Data from the Junior High School, Redlands, California, September, 1940.)

There may be sharply increased percentages of older pupils in the eighth grades of 8-4 systems and in the ninth grades of 6-3-3 systems because of unmet standards for advancement into the next division of the system. When these systems attempt homogeneous grouping, the retarded pupils are generally segregated into one or

two sections on each level. Since these pupils are usually the older individuals, there is a narrower age range in the remaining sections.

Physical range. The three years of the early secondary school see the greatest range in physical development. In the seventh grade, and occasionally in the eighth grade, there are usually one or more children, physically speaking, recognizable by their large heads, slight bodies and slender limbs. But most of the pupils in the seventh and eighth grades are already showing the beginnings of adolescence even though they have not matured sexually. Most of the boys in the ninth grade are in these early stages of adolescence.

A few sexually mature girls will be found in the seventh grade, still more in the eighth grade, and a majority of those in the ninth grade will have passed into puberty. Boys are slower maturing but a fair number of them will have become physical adolescents in the ninth grade. The fact that boys and girls arrive at sexual maturity at different times, and the fact that some individuals of each sex mature before others, causes endless problems for pupils and teachers alike.

Sudden increase in size and sudden change in body proportions cause unaccustomed stresses on muscles and joints. Young people react by wriggling about and standing or sitting in odd positions. The reaction is normal and should be expected when pupils are required to sit quietly for long periods. Science lesson plans need provision for intervals of physical relaxation. Short field trips, laboratory work, and projects may be alternated judiciously with sedentary activities, not only to improve instruction, but also to provide for the physical needs of growing youngsters.

Sudden growth is often attended by self-consciousness and awkwardness. Accidents and breakage of equipment are bound to occur. Problems are apt to be especially acute when an individual is forced to be the center of attention. It is never wise to insist that a self-conscious individual present a demonstration or an oral report without the support of one or more of his classmates. Self-conscious individuals usually work well in teams but are miserable when compelled to stand alone before a class.

Throughout the period of physical change, fear and worry about what is taking place in their bodies can be reduced by giving the pupils proper understandings. Adolescents are especially in need of information about ways to take care of themselves. A unit on growing up can be of real service.

Psychological development range. A number of pupils enter the seventh grade while still children, psychologically speaking. Some are young in years, some are young physically, and some have been

shielded from social contacts. Most of these individuals mature rapidly; few children in the true sense of the word are found in the junior high school.

General science teachers first encounter most of their pupils in the stage known as "preadolescence." Girls usually pass into puberty during these years but some of the boys are still preadolescents at the close of the ninth grade. The eighth and ninth grades show the greatest cleavage between boys and girls, most of the girls having become adolescents while many boys remain preadolescents. Teachers have serious problems equating the groups.

Preadolescence is a particularly trying stage. Young people are discarding the known ways of childhood and groping their ways towards maturity. General science teachers need special insight, sympathy, and tolerance if they are to help boys and girls through this difficult period. They also need a good deal of personal stability to deal with the various personal problems that may arise.

All teachers in the early secondary school need a sound understanding of the characteristics of preadolescence and early adolescence. Below are given some of the more common characteristics observed in preadolescents:

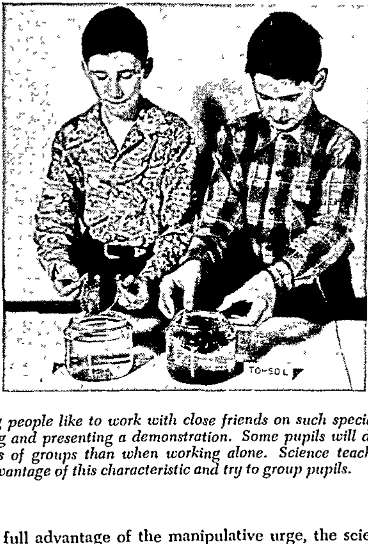
1. Restlessness
2. Mood instability
3. Conflict of sophistication and childishness
4. Body anxieties
5. Formation of peer groups of the same sex
6. Tribal warfare against adults
7. Guerrilla warfare within the home
8. Intensity about minor issues
9. Awakening sex interests and smuttiness
10. Boy-girl conflicts
11. Ambivalent feelings toward parents, teachers, siblings
12. Day-dreaming
13. Nervous habits
14. Desire for privacy
15. Pride in possessions [1]

Restlessness, of course, is troublesome to all teachers. Although the trait is a perfectly natural one, traditional schools of the past have tried to suppress it. The effort has been an unhappy one for both pupils and teachers. An easier solution is to provide variety in the program, using many different types of activities and alternating activities of completely different nature with each other. Giggles,

[1] Adapted from Wattenberg, W. W., *The Adolescent Years*, Harcourt, Brace, New York, 1955.

shouts, and squeals, perhaps at the climax of a demonstration, are expected, planned for, and recognized as important ways to relieve tensions.

Young people like to manipulate materials. A boy may enjoy watching an electric motor run but if he has the opportunity he will soon be handling it—slowing it with his finger, starting it, stopping it, perhaps taking it apart. *Girls show less interest in mechanical things, probably* because of cultural influences, but they like to experiment with chemicals and biological materials, and they usually enjoy making charts, clay models, and posters.



Most young people like to work with close friends on such special activities as preparing and presenting a demonstration. Some pupils will do far more as members of groups than when working alone. Science teachers should take full advantage of this characteristic and try to group pupils.

To take full advantage of the manipulative urge, the science classroom should be full of "things"—tools, wire, wood and other raw materials. There should be motors, buzzers, and a wealth of similar devices. As much as possible, these things should be put out where pupils can

work with them during their free time. All lesson plans should provide intervals during which pupils are encouraged to manipulate.

Possessions take on added value during early preadolescence. Boys and girls may start collections of almost anything from match folders to soda bottle caps. This is a trait of value to the science teacher who may encourage pupils to begin systematic collections of leaves, rocks, minerals, fossils, seeds, and the like. It is not to be expected that a boy who collects fossils will become a paleontologist, or a girl who collects butterflies will become an entomologist. Collections are important because through them pupils gain important experiences, and because, in making them, pupils learn about themselves and find satisfaction in accomplishment.

The urge to manipulate and the urge to possess fuse into and blend with the desire to create. Teachers of crafts, homemaking, and agriculture capitalize upon this trait. In science, there are unlimited opportunities for pupils to create tangible things—models, charts, posters, friezes, demonstration materials, and the like. They may work at school or at home or both. They may display their achievements before the class, in school corridors, and at science shows.

In all types of work, preadolescents show a growing desire to work with their friends. This is part of the developing gang spirit. Science teachers may utilize this trait in endless ways. Pupils may work on projects, they may do field work, and they may make presentations to the class—all as members of small teams. Indeed, many pupils will undertake tasks with their friends that they would never consider doing alone.

One phenomenon of preadolescence is sex hostility. Many pupils will refuse to work with members of the opposite sex. Some, if forced to do so, will be miserable; others will openly rebel. This is a trait to be considered when planning for group work.

There is no sharp distinction between psychological preadolescence and adolescence. Many preadolescent traits persist into adolescence and gradually disappear as young people develop new concerns, as the conditions that caused insecurities end, and as new habits of behavior are formed. Perhaps the most marked personality change is the end of boy-girl conflicts and the increased pleasure the two sexes find in each others' company. Some of the special traits of adolescence are:

1. Desire for adult status
2. Concern with social status
3. Development of tightly-knit cliques
4. Intergroup warfare
5. Dating prestige
6. Development of ideals

7. Modification of conscience
8. Sexual experimentation
9. Practice of adult roles

Adolescents want, and often demand, adult privileges. Many of these young people, especially those who have jobs or take an adult's responsibility in the home, deserve some of these privileges. All adolescents need opportunities to prepare themselves for maturity.

In school, boys and girls can be given responsibilities fitted to their varying degrees of maturity. They can help in planning and carrying out the regular activities of the classroom. At the beginning they may take upon themselves only the conduct of a demonstration or the solution of a minor problem. As they gain in experience they can help plan lessons and even full units.

Failures must be expected when young people have had no practice with mature roles. But failures should result not in curtailment of privileges but rather in a reexamination of the conditions that resulted in failures. For example, a tenth grade biology class should be able to govern itself for the better part of a period without teacher supervision. Failure to do so may be due to any one of a number of factors. Perhaps the pupils had not been given sufficient practice in controlling themselves for so long a time; perhaps the pupils did not have well-defined and meaningful tasks to keep them occupied; perhaps some of the pupils completed their work and had nothing to do; or perhaps there was not enough variety in the activities to hold attention for so long a time.

Intellectual range. The early secondary school grades have pupils with about the same range of intellectual ability as the general population. Because schools are somewhat selective, some of the less able pupils are held back, placed in special classes, or dropped from school. This gives a slightly irregular curve like the one shown in figure 1. However, as the holding power of our schools increases, the curve will approach more closely that of the general population.

One frequently used label for indicating mental ability is the intelligence quotient, or IQ. *General science teachers will frequently find* pupils with intelligence quotients ranging from 75 to 160. Pupils with lower ratings are usually put into special classes under the care of specially trained teachers.

Another label used to indicate intellectual ability is mental age, which is used in the determination of the intelligence quotient. IQ is the ratio of mental age to chronological age. Mental age tends to keep pace with chronological age until about age thirteen, after which the rate of mental growth begins to slacken. Mental growth as meas-

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ured by tests practically ceases after age sixteen for the average population.

The mental ages of pupils in the general science program may range from nine years to seventeen or eighteen years with occasional extremes beyond these limits. Table 2 gives the variations that may exist in a single junior high school.

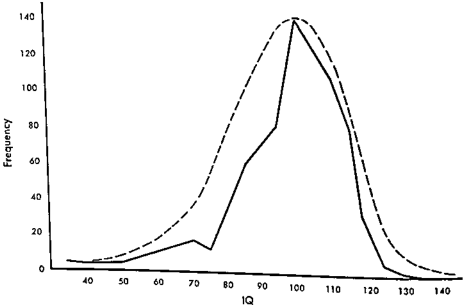

FIGURE 1. *Distribution of intelligence test scores in a junior high school. Dotted line represents the distribution of intelligence test scores for an equivalent segment of the general population.* (Data from the Redlands, California, Junior High School, 1940.)

General science teachers should interpret intelligence test scores with caution. High scores usually indicate ability to do satisfactory academic work in high school and college. Their chief value to the general science teacher comes from helping him locate pupils who are not working up to capacity.

Low scores on intelligence tests may be due to (1) low inherited ability, (2) inferior cultural background, (3) misunderstanding of directions on tests, (4) physical or emotional disturbance while being tested, (5) carelessness due to poor attitude towards school and school work. A low score does not predict certain failure in academic work nor lack of high ability in areas other than academic.

General science teachers should not allow themselves to be prejudiced against pupils with low scores on intelligence tests. Such pupils often do a higher quality of work than might be anticipated because of

Mental Age	*Number of students* Low grade 7	*Number of students* High grade 9
18-0 to 18-5	0	13
17-6 to 17-11	0	49
17-0 to 17-5	1	78
16-6 to 16-11	2	112
16-0 to 16-5	5	132
15-6 to 15-11	17	199
15-0 to 15-5	38	216
14-6 to 14-11	86	231
14-0 to 14-5	160	226
13-6 to 13-11	227	215
13-0 to 13-5	328	186
12-6 to 12-11	374	150
12-0 to 12-5	254	145
11-6 to 11-11	234	65
11-0 to 11-5	101	29
10-6 to 10-11	26	10
10-0 to 10-5	7	3
9-6 to 9-11	3	0

TABLE 2. *Mental ages of pupils entering and leaving the junior high school grades.* (Data from public schools, San Francisco, California, 1933.)

special interest and effort. They frequently do excellent work with tools, science apparatus, and art materials. These pupils deserve opportunities for growth just as do the higher scoring pupils. Fortunately, the science program can provide opportunities for all types of intellectual ability.

Many school administrators attempt in the junior high school what is called "homogeneous" or "ability" grouping. In theory pupils with nearly identical abilities are grouped into separate sections. The principle behind this type of grouping is that learning can take place more effectively if the variations in learning abilities are reduced in range. The problem, of course, is how to make the division.

The most common basis for grouping is mental age, intelligence quotient, scholarship marks, achievement test scores, or a combination of any of these. Grouping of this type on the basis of academic ability greatly narrows the academic range in any one section.

In the well rounded science program, however, many types of talents are utilized. Homogeneous grouping in science therefore cannot be approximated because a pupil high in one type of ability may be low in another. Actually, a range of different abilities is helpful in the science program and provides stimulation to both the teacher and the pupils.

Range of reading ability. Table 3 indicates the range of reading abilities that may be expected in a general science class. The full range may not be encountered in any one school, socio-economic background being one factor in the development of reading ability, and sectioning may reduce the range in any one class if academic ability is used as a basis for sectioning.

The range given in Table 3 should cause no amazement nor consternation. A variation of several years in reading age within any grade is normal.[2] Secondary school teachers have closed their eyes to this obvious fact all too often and have treated all pupils in a class as being at the norm or above in reading ability. The result has been failure and unhappiness for many boys and girls.

Reading Grade level	*Frequency*
Below grade 4	138
Grade 4	353
Grade 5	672
Grade 6	1006
Grade 7	1270
Grade 8	1032
Grade 9	1121
Grade 10	820
Grade 11	497
Grade 12	286
Grade 13 and above	185

TABLE 3. *Distribution of scores of 7380 eighth grade graduates on the* Traxler Silent Reading Tests, *June 1943 and January 1944 classes in St Louis.*

Retardation in reading is due to a number of causes, most of which have little to do with native ability. Some of the reasons are listed below:

1. Visual defects
2. Malnutrition
3. Fatigue
4. Neurological conditions
5. Auditory and speech factors
6. Language difficulties (especially in foreign language homes)
7. Mental ability
8. Personality maladjustments
9. Home conditions

[2] Strang, Ruth, "Providing Special Help for Retarded Readers," *Reading in the High School and College*, Part II, The Forty-seventh Yearbook of the National Society for the Study of Education, The University of Chicago Press, Chicago, 1948.

10. *Interruptions of schooling by illness*
11. Frequent moving from school to school
12. *Unsatisfactory teaching in earlier grades* [3]

Pupils who read below grade level should never be regarded as "impossible." Most of them have many potentialities that can be developed. Some need special help from trained reading specialists, but many need little more than help in developing reading interests and self-confidence.

The great challenge to a general science teacher is to present a stimulating and rewarding program for retarded readers while at the same time encouraging advanced readers to make the most of their capabilities. General science lends itself to this type of program because the emphasis at the beginning of each topic can be on learning through first-hand experiences—experiments, demonstrations, field work—in which all pupils participate equally. The follow-up activities can then make use of the different talents which pupils have.

The range of reading abilities shown in Table 3 indicates that a textbook cannot be used as a single source of information for all pupils. This is especially true because most general science texts have a reading level equal to or above the grade level for which they are designed, and in addition make use of a specialized vocabulary that many pupils do not understand. A teacher may use a single text as a basis for the program in his classes, but he must amplify this with many other books, including those written for lower grade levels. Fortunately, the catalog of simply written, well illustrated, and valuable science books for children is increasing rapidly.

Range of experience background. The experience background of pupils is an unpredictable factor of great importance to science teachers. Boys and girls who have travelled extensively, read widely, and shared in the many experiences of home and community are at a definite advantage in the science program. They have wider interests, they make more applications of material studied in class, and they understand better the importance of the material they study. In contrast, pupils who are underprivileged in terms of background must be shown many things that others will take for granted.

The range of experience backgrounds is always wide, even in a school that services a fairly homogeneous community. Boys and girls who live next door to each other will have travelled to different places, read different books, met different people, and shared in different home activities. This type of range can be valuable to the science teacher

[3] *Ibid.*

who makes use of the resulting interests to stimulate different kinds of activities in the classroom.

The truly great ranges come in a school that services widely differing sections of a community. The fortunate pupils are those who come from homes where parents give attention to their children, and where there is money for travel, for magazines, music and books, and for constructive hobbies. The pupils who come from homes where parents ignore their children and where there are no cultural influences have backgrounds limited to the experiences they pick up on nearby streets.

These latter pupils are handicapped from the beginning. School activities generally have less meaning to them. They progress less rapidly, they find less satisfaction in school, and they develop fewer favorable attitudes towards school work. They make up the bulk of the retarded readers and the average pupils. There is even limited evidence that their general intelligence is affected.

Frequently these underprivileged boys and girls are hopelessly handicapped in academic work by the time they enter the seventh grade. The general science teacher must use special care that he does not deepen their sense of inferiority. If he will emphasize learning through firsthand experiences, using techniques that do not depend upon reading or upon cultural background, he will find these pupils responsive, often enthusiastically so. And once these pupils discover that they have ability, as most of them do have, they grow rapidly.

Pupil backgrounds vary also because of previous schooling. Junior high schools usually bring together pupils from several elementary schools. A seventh grade general science teacher may expect considerable variation in the educational backgrounds of pupils from different schools. This refers not only to skills developed and to facts learned, but also to experience with different teaching methods and to attitudes developed towards school work in general.

Some systems stress drill and mastery of skills in computation and reading. Some schools strive for all-around development of children. Some, because of the nature of their pupils, can set higher achievement standards than others. There are those that use only formal procedures. Others use all types of modern teaching techniques.

Such variation is bound to affect the teaching of general science. Pupils who enjoy books will turn freely to reading materials if such are available. Pupils who dislike reading will read a minimum amount no matter how well they have mastered basic skills. Different procedures must be used with each type of pupil for satisfactory general science instruction.

Pupils who have experienced only formal teaching methods may not

know how to participate in informal group work. Pupils who have known only free classroom work with a maximum of pupil-teacher planning, informal group activities, and individualized instruction, may be very unhappy in a rigidly formal general science class.

General science teachers must consider the educational experiences of their pupils when organizing a program. It would be folly to start a completely free program on the first day with pupils who have always been held in strict discipline. Such pupils need time for adjustment; they profit best from short periods of informal activity during which they learn how to conduct themselves and how to profit from the occasions. As their facility grows they can be given greater responsibilities.

General science teachers should also plan to use the special skills developed by the pupils who come to them. The pupils who have had a rich elementary school science program can repeat demonstrations and projects they worked on in the elementary school, this time to instruct their classmates. Pupils who have had leadership experience can be the first leaders in small group activities in the general science classroom. Pupils who read well can do book research and report to the remainder of the class. It is thus that each boy or girl can continue to grow rather than be held to the pace of a rather low average group.

PUPILS IN THE ELECTIVE SCIENCES

Teachers of the elective sciences encounter no such extreme ranges as do the teachers of general science. The fact that these young people have elected science courses indicates a greater uniformity of interests, abilities, backgrounds and purpose than is found among pupils in general science. In consequence, the elective sciences tend to be comparatively homogeneous.

This does not imply that pupils in the elective sciences are so much alike that they demand uniform teaching procedures. These young people are still individualists and they still have variations in interests and abilities that make individualized teaching desirable.

Age ranges. Most of the pupils in the tenth year of school are fifteen or sixteen years old. There are a few younger pupils who have accelerated and a larger number of pupils who have been delayed by late starts, by illnesses, or by repeating grades. In the eleventh grade, the majority of pupils are sixteen or seventeen years old and in the twelfth grade the majority are seventeen or eighteen years old. The age range in each succeeding grade tends to narrow as the older pupils drop out of school before graduation.

Of the three major electives, biology tends to have the greatest range of ages. It is offered in the tenth year to most pupils but frequently eleventh and twelfth year pupils elect it. Expected ranges can be from fourteen years to nineteen years, with most of the pupils in the fifteen and sixteen year old groups

Chemistry and physics, usually eleventh and twelfth grade subjects respectively, have a correspondingly narrower age range. Because few retarded pupils elect these courses, the members of physics and chemistry classes are generally made up of the younger and more successful pupils in their respective classes. The majority of them are sixteen, seventeen and eighteen years old.

Physical range. With the exception of a few cases of delayed maturity, most of the pupils in the elective sciences have reached puberty. The girls have achieved full growth. The boys are growing slowly in height and weight. Physically, most of them are adults and are capable of the same physical activities as adults. There may be a few late maturing girls and a few more late maturing boys. The latter are under special handicaps in games, athletic contests, and in their relationships to girls of their own age.

Psychological range. Whereas general science contains pupils in all states of development from childhood to adolescence, the pupils in the elective sciences are preponderantly adolescents. Their range of behavior is consequently much narrower. And even as adolescents, these pupils do not exhibit the same extremes of behavior as do the adolescents in general science.

For one thing, these pupils are older. They are losing some of the self-consciousness that causes the unusual behavior of junior high school pupils. They are also facing the problems of the future more closely and this has a sobering effect upon many of them. By the time these pupils become seniors many of them have become almost adult in their reaction to commonplace situations.

Their desire for adult status has strengthened. Girls of this age often assume adult responsibilities in housework and in the care of children. Boys earn spending money, drive cars, and participate in athletic games on an equal status with adults. Such older adolescents are apt to insist that they be treated as adults and they resent openly situations that give them any lesser status.

The influence of others of their own age is still strong but as they become older and more adult in thinking, the gap between themselves and older people narrows. They listen to and cooperate better with adults except when the latter try to treat them as children.

As these adolescents approach graduation and the problem of their

life work, they begin to think more in terms of the distant future. In the lower secondary school, their immediate problems were too pressing to allow much consideration for conditions that they might face eight or ten years later. But as older adolescents, they undertake tasks for which they can see future advantage.

Young people like to manipulate science materials. Boys may be more interested in mechanical and electrical devices than girls, but the latter can find great satisfaction in most of the activities of the science program. The teacher should allot as many responsibilities as possible to the pupils.

Sex distribution in the elective sciences. Table 4 gives the percentages of boys and girls in the commoner high school sciences. The general science courses are usually mandatory so the figures reflect the sex distribution of the school population for each of those years. There is a slightly greater number of girls than boys because our general population contains a slightly greater number of girls and because more boys than girls drop out of school in the early secondary school years.

Biology seems to appeal to boys and girls about equally. The figures given are about the same as the sex distribution for the tenth grade as a whole, the tenth grade being when most pupils take biology.

More boys elect chemistry than do girls. This may be because science appeals more to boys than to girls. It may be that a number of boys elect chemistry because it is required for or recommended for admission to the technical colleges they plan to enter. Some girls elect chemistry because of possible use in nursing and home economics.

Subject	*Boys*	*Girls*
General science, 7th	49.6%	50.4%
General science, 8th	48.0%	52.0%
General science, 9th	48.0%	52.0%
Biology	46.8%	53.2%
Chemistry	55.6%	44.4%
Physics	71.1%	28.9%

TABLE 4. *Distribution of pupils by sexes in the secondary school sciences.* (Taken from data given by P. G. Johnson, *The Teaching of Science in the Public High Schools,* Bulletin 1950, No. 9, U. S. Office of Education, 1950.)

Physics classes are composed preponderantly of boys. By tradition physics is a boys' subject and there is no attempt to make it appeal to girls. This is unfortunate because girls need a knowledge of physics as much as boys do.

Intellectual range in the elective sciences. The selective factor greatly narrows the range of intellectual abilities in the elective sciences, particularly in such traditionally academic courses as physics, chemistry and biology. For one thing, the median level of intellectual capacity tends to rise as unsuccessful pupils drop out. Of those remaining only those with demonstrated academic ability are encouraged to elect the advanced sciences and in some schools they are the only ones permitted to do so.

The median IQ for the general school population rises appreciably through the senior high school grades. This is due to retardation and dropping out of pupils who are less gifted academically. If the future holding power of a school increases, these figures may decrease.

As will be shown in chapter 4, about 70% of the tenth year pupils elect biology. Assuming that these represent the more academically gifted pupils, nearly all the pupils above the median IQ must elect it. There must also be a substantial number of those below the median. However, it is doubtful if many pupils with an IQ below 90 elect biology and probably most of them have an IQ above 95.

School policy may narrow the range even more. If the school offers biology only to pupils in the college entrance program, most of the pupils have an IQ above 110. If, on the other hand, biology is re-

quired to satisfy health requirements, the range is about the same as that for the general school population.

Assuming that chemistry is elected in the eleventh year, about 30% of the pupils in that grade take that subject. It is safe to predict that most of the pupils in chemistry come from the upper third of the class and that few pupils with an IQ below the median 103 are encouraged to elect it. In schools with a rigorously selective college entrance program, most of the pupils in chemistry are above the minimum IQ of 110—a number which is often set as the cut-off point. Other schools permit a greater range.

Physics is considered to be the most rigorous of the high school sciences. Its very reputation serves to eliminate many pupils. Physics is generally given in the twelfth year and it is estimated that about 20% of the pupils in that year elect it. It is probable that most of those electing it come from the upper quarter of the class and that few with IQ's below 110 ever consider taking it.

The range in other elective sciences is completely unpredictable. Earth science may be given to provide a science course for pupils without the ability to succeed in the usual biology, physics or chemistry courses. It may, on the other hand, be given to a highly selected few, or it may be open to anyone interested. Ranges vary correspondingly. Local policies must be examined before making estimates.

IQ	*Biology*	*Chemistry*	*Physics*	*Earth science*
80-84	0	1	0	0
85-89	1	0	0	0
90-94	1	1	1	0
95-99	5	3	5	2
100-104	6	5	2	2
105-109	21	9	10	3
110-114	19	9	6	2
115-119	16	13	14	4
120-124	11	4	4	8
125-129	9	5	3	3
130-134	0	0	0	1
135-139	0	0	0	0
140-144	2	2	2	0

TABLE 5. *Distribution of intelligence quotients among the pupils electing senior high school sciences in a senior high school during the year 1956-57.* (Data courtesy of the Solvay, N. Y., Public Schools.)

Table 5 gives the distribution of intelligence quotients of the pupils in the elective sciences of a small senior high school in New York State. The state wide system of final examinations in these subjects

serves as a selective factor which operates even without administrative policy fixing

The range of reading abilities. Physics, chemistry and biology are generally taught as highly academic subjects. Pupils with inferior reading abilities rarely feel competent to elect them. In some schools, policy permits only pupils with good academic records, namely the good readers, to elect advanced sciences. In some systems, all pupils with good academic records, again the good readers, are strongly encouraged to enter the college preparatory program which includes one or more science electives.

These factors operate to concentrate the better readers into the three major science electives. Table 6 shows how effective these forces are.

Reading Age	*Biology*	*Chemistry*	*Physics*	*Earth Science*
7·0-7:5	1	0	0	0
7:6-7:11	0	0	0	0
8.0-8:5	0	1	0	0
8:6-8:11	0	0	0	0
9:0-9:5	1	0	1	0
9:6-9:11	1	0	1	0
10:0-10.5	1	3	0	0
10:6-10-11	2	0	0	0
11:0-11:5	2	3	4	0
11.6-11:11	2	1	0	0
12:0-12:5	6	2	2	0
12.6-12:11	1	0	2	0
13:0-13:5	5	3	4	1
13:6-13-11	5	1	1	2
14:0-14:5	5	1	3	3
14:6-14.11	5	1	3	2
15:0-15:5	11	9	6	1
15:6-15:11	9	4	4	4
16:0-16 plus	35	21	16	12

TABLE 6. *Distribution of reading ages in the elective sciences in a single school for the year 1956-57.* (Data courtesy of the Solvay, N. Y., Public Schools.)

No teacher can assume on the basis of this table that there are no reading problems in biology, physics, and chemistry. There are many. There is a difference between reading general material and scientific material. There is also a difference between being a good reader and a willing reader; many pupils can read science materials but they prefer not to, a condition which some teachers consider laziness but which may represent the existence of competing interests. In addition,

teachers must recognize that many science books employ unnecessarily technical vocabularies and difficult sentences and paragraphs.

Elective sciences added to the curriculum for boys and girls of lesser academic abilities necessarily show a greater range in reading abilities. These courses include more pupils who are retarded readers, and under some policies they may include few superior readers. Such elective courses must be planned with the nature of the reading problem in mind. Emphasis should be placed upon learning through first-hand experience situations. Films, slides and recordings should be used more extensively than books for supplementary sources of information. The books used should be selected carefully on the basis of readability, usefulness of illustrations, and relation to the firsthand experience situations used. If possible, there should be many different books, including many designed for the elementary school. Everything should be done to make science reading interesting in these courses.

Suggested activities

1. Obtain the ages, IQ's, and reading levels of one or more science classes. Prepare histograms to show the frequency distributions of these characteristics in each class.

2. Observe one pupil carefully throughout a full science period, making detailed notes on his behavior. Try to account for each of his actions as a response to the situation in which he finds himself.

3. Make a study of a pupil of high IQ and another of low IQ in the same class. Through classroom observations note differences in response to different situations. Study their written reports and their test papers. Try to determine the nature and extent of the changes in each pupil as a result of his science work throughout your period of observation.

4. Suppose that you are a teacher of a biology class similar to that for which Tables 5 and 6 have been prepared. What are some things you could do to provide the best possible learning situations for these pupils?

Suggested readings

Adolescence, Forty-third Yearbook of the National Society for the Study of Education, University of Chicago Press, Chicago, Illinois, 1944.

Blair, A. W., and Burton, W. H., *Growth and Development of the Pre-Adolescent,* Appleton-Century-Crofts, New York, 1951.

Wattenberg, W. W., *The Adolescent Years,* Harcourt, Brace, New York, 1955.

HOW BOYS AND GIRLS LEARN SCIENCE

chapter 3

On Monday at 10:15 in general science class, Ted was confronted with the problem of connecting a dry cell, a push button, and a door bell in a workable circuit. The problem appealed to Ted but he found himself with little idea of what to do. He fumbled uncertainly with the materials for a few minutes, then turned to a diagram in his textbook for help. At 10:35 he succeeded in sounding the bell by pressing the button.

Without analyzing the situation himself, Ted nonetheless felt satisfaction in his accomplishment. He had two observations of himself by which he could measure progress, the first at 10:15 when he realized that he did not know how to make the proper connections, the second at 10:35 when he succeeded in making the bell ring.

Ted's teacher, Mr. Bowers, also had two observations by which he could measure Ted's progress. He noted Ted's indecision when the problem was first presented. He saw Ted succeed in ringing the bell.

Mr. Bowers was able to recognize certain other learnings during the lesson. For one thing, he had noticed previously that Ted rarely referred to books for help. On this particular day, however, he saw Ted use his textbook successfully. This implied to Mr. Bowers that Ted had progressed slightly in the use of books. Ted, however, was not at all conscious of this aspect of his growth, because he did not make observations of his own behavior.

Mr. Bowers' lesson plans were developed with both kinds of learnings in mind, the kind of which Ted was conscious and the kind of

which only the teacher was conscious. The former type of learning included subject matter learnings and improved skills. The latter type included changed attitudes and changed habits of doing things.

During his planning, Mr. Bowers was concerned with what his pupils could learn and how they could learn it. He wanted to utilize situations in which pupils would sense their own accomplishments and, at the same time, he wanted these situations to help him attain his broader goals.

THE POINT OF VIEW OF THE LEARNER

Learning is usually judged from the viewpoint of an outsider looking at the accomplishments of a pupil. Rarely are the feelings and judgments of the pupil taken into consideration, and, as a result, there is much misunderstanding and discouragement on the part of both teacher and pupil.

The following represents part of a conversation between an adult and a high school pupil concerning the workings of a core-type program:

Adult: What are you learning in this core course?

Pupil: We're not learning anything very much.

Adult: What do you do in class?

Pupil: Oh, we sit around and talk and try to decide on something we would all like to do. Then we do it.

Adult: Have you made any progress?

Pupil: Yeah, at the beginning it used to take us two or three weeks to decide what we wanted to do, and now we can ordinarily do it in a day or so.

Adult: Why is that?

Pupil: Oh, we keep on the subject better than we used to. At first everybody popped off with any idea that came into his head; now we listen more carefully and keep on the subject matter.

Adult: Everybody doesn't talk at once any more.

Pupil: Yeah, that's it. Last September, too, there were two or three kids who did all of the talking. Now almost everyone takes part.

Adult: Do you have any reports from the students in class?

Pupil: Yeah, at the end of our units.

Adult: Are the reports pretty good?

Pupil: At first they were terrible. Nobody worked on his very hard, and we were all bored to death.

Adult: Are they better now?

Pupil: Yeah, I think the reports are a lot better. We pay closer attention, too.

Adult: But you haven't really learned anything?

Pupil: That's right.[1]

This conversation pictures a situation in which a teacher might feel well satisfied with progress towards certain goals which he has set up for a course. The pupils, however, were not conscious of important achievements. Pupils do not make observations of themselves in the same way that teachers make them. They tend to think of progress in terms of concrete accomplishments.

Objectives for teachers and pupils. General educational objectives are rarely good goals for pupils. Pupils are not usually conscious of their long term needs. They do not observe their own behavior patterns in sufficient detail or critically enough to be conscious of long term progress. Even when they are made conscious of their general needs, the goals are too slowly attained to be suitable for young people. Pupils need immediate objectives, which they can attain in a short time.

Traditionally, schools use subject matter goals. Both pupils and laymen expect learnings in terms of subject matter. Without them, they consider a school program to be a failure.

Frequently, subject matter goals are so poorly chosen that they defeat the purposes of schools. If a pupil cannot see value in the subject matter he is learning, he will be dissatisfied. One of the reasons for dropouts is the feeling that the school program is not making worthwhile contributions.

Even though pupils and laymen expect subject matter learnings as an outcome of education, pupils rarely set up subject matter objectives for themselves. Their objectives are more in terms of actually doing things, of producing tangible results. Referring to the objectives of Ted and Mr. Bowers in the situation previously described, there are two sets of parallel objectives:

Ted's goal

To set up a door-bell circuit that will operate properly

Mr. Bowers' goals

To give Ted practice in a problem-solving situation
To encourage Ted to use books more freely
To help Ted gain skill with tools and materials
To increase Ted's sense of competence
To increase Ted's interest in the study of science
To give Ted some knowledge of electric circuits

[1] Eserer, P. E., and Corey, S. M., "How Youth Learn to Meet Their Needs," *Adapting the Secondary-School Program to the Needs of Youth*, Fifty-second Yearbook of the National Society for the Study of Education, The University of Chicago Press, Chicago, 1953.

Ted accomplished his objective in twenty minutes. Mr. Bowers' objectives were too broad to be attained in a single lesson, but as Ted worked toward his own objective, Mr. Bowers could see progress toward some of these broad objectives.

Pupil objectives determine the effectiveness of a science course. Whatever is accomplished depends upon what the individual pupils set out to do. Teacher objectives mean nothing if pupils do not have objectives as well.

Success in setting up objectives that pupils will accept as their own demands that a teacher put himself in the position of each pupil as completely as he can. To do so he must have a thorough acquaintance with his pupils as individuals.

Pupil goals should give pupils a sense of accomplishment. The more real and tangible the outcomes, the more satisfaction pupils gain. For example, a large chart made and exhibited means more than the same information learned. A successful pupil demonstration means more than a perfect score on a quiz. Participation in a science radio program means more than a high grade on a final examination.

Even as pupils accomplish tangible things, they can be given a sense of achievement in terms of subject matter. The production of an assembly program in science does not emphasize learning of information but pupils do learn a great deal while engaged in the activity. The extent of their learnings is easily pointed out to them by an oral review and a few purposefully designed tests.

The attainment of pupil objectives should of course contribute toward the broad objectives of the science program. Sometimes the subject matter learned is of greatest importance, as when information learned about bacteria leads to wise health practices. More often it is the type of activity engaged in that is of importance, as when pupils write reports or give talks or use tools. Generally, one pupil objective parallels several broad educational objectives and helps in their attainment.

harmonics. The girls studied hair styles and eye glass frame styles for various types of faces. The boys studied color combinations of ties, shirts socks and suits.

A large triple mirror was brought in so that each pupil could see how he looked while standing and sitting. Committees judged posture while walking and climbing stairs. Bulletin boards and posters showed good and poor posture and uses of clothes to minimize physical defects.

The unit culminated in a school-wide "dress-up" day sponsored by all teachers and homeroom organizations. Pupils tried to dress in the best taste possible. Homerooms voted on the best dressed girl and the best dressed boy in each room. Good grooming and good taste were stressed rather than quality of clothing.

Miss Timmons' use of adolescent needs to motivate a unit on cleanliness and personal health makes motivation seem rather simple. Actually motivation is exceedingly complex. It involves many factors. The motivation of adolescents with their many new and poorly understood needs is especially unpredictable.

The general tendency is to oversimplify motivation by lumping all motivating factors under one heading which is labeled "interest." Interest is then treated as something definite that can be described and measured, something that is shared by whole groups of pupils.

Interest is the manifestation of a felt need. Two pupils may show identical interests in the same topic but their interests may result from completely unlike needs. One boy, for instance, may show special interest in repairing a lamp cord because he wants to repair one in his room at home. The second boy, his close friend, may show the same interest because he wants to work with his friend. Two girls may show a strong interest in birds, one because she wants to share her father's interests, the second because she wants to engage in a solitary activity that gives her an appearance of aloofness.

As needs change, interests change. New friendships, changed social status, revised feelings of security, all result in new needs and new interests. The addition of a single new person to a class can influence the interests of all other members of the class. Rarely can a teacher predict interests with a high degree of accuracy.

Mrs. Lyons developed a unit called "Our Weather Bureau" for her eighth grade science class. It was the most successful unit of the year. Her pupils made weather instruments, they kept excellent records, and they maintained a bulletin board in the main foyer where they posted both their predictions and those clipped from newspapers.

The following year Mrs. Lyons decided to teach the same unit again. She followed the previous year's plans exactly, using the same approaches

and the same activities. The unit was a failure. She never understood what was wrong.

It is useless to try to diagnose the causes for Mrs. Lyons' successes and failures in the two situations Only a careful observer on the scene through both episodes could discover why the study of the Weather Bureau met the needs of one group of pupils and not the needs of the other. Mrs Lyons' error lay in assuming that the interest of one group would be the same as the interest of another. She based her plans on interest rather than on needs, unlike Miss Timmons, whose unit on personal grooming was fitted to adolescent needs.

Interest must not be discounted as an unimportant element in science teaching. The needs of adolescents are generally so complex and so ill-defined that they cannot be analyzed by the classroom teacher. High interest can be interpreted as a sign that needs exist even when these cannot be identified.

LEARNING SCIENCE SUBJECT MATTER

Because the major function of schools has long been assumed to be the teaching of information, more research has been done on this phase than any other. In consequence, there is considerable knowledge about the ways boys and girls learn facts. Most of this knowledge can be applied readily to the teaching of science.

How learning begins. Learning is a result of association. The small baby associates his mother with the pleasures of feeding. He associates crying with attention. Later he associates a cup with drinking and a "toddler car" with increased independence of motion.

He learns language the same way. He associates the syllables "mama" with his mother. He associates "no" with denials or punishment. In every case, learning is the result of association of experiences. The burnt child associates steaming food, or flames in the fireplace, or an unshielded stove, with pain. The unburnt child has no fear of these things. In learning language, the child who has been burnt is able to associate the word "hot" with objects that can burn him. To the unburnt child, "hot" is a meaningless and somewhat pleasant syllable to repeat over and over. It is a nonsense word.

In science, as in other subjects, true learning is not a memorization of nonsense syllables, but the result of association of experiences. Without experiences there can be no science learnings.

Jack and Joe are two members of an eighth grade science class that is studying the nature of fire. Spontaneous combustion is one topic under

consideration. Jack lives on a farm where a fire once leveled a large barn, destroying livestock, crops and equipment and causing great hardships for the family. Joe lives in a large village where there have been no serious fires in his lifetime; his experiences with grass fires and chimney fires have been pleasurable and exciting.

The textbook explanation of spontaneous combustion had immediate significance to Jack. He knew how hay is made and stored. He had noticed heat in fermenting manure and piles of wet grass. He could see a possible relationship to the loss of his father's barn. He turned to additional books including a chemistry text.

Joe, on the other hand, had only a limited experience with hay. He could not conceive of wet hay setting itself on fire. The term "spontaneous combustion" was little more than a nonsense syllable and he was impatient to turn to a new topic.

Joe needed mental images of conditions in which spontaneous combustion takes place. He might have gained these by listening to Jack describe the fire in his father's barn. He might have gained them by reading vivid descriptions of fires caused by spontaneous combustion. With the images thus produced he would be better able to appreciate the importance of the topic and would thus be more ready for study.

A number of classroom experiences could have been provided to prepare him for the textbook explanations. He could have discovered that heat is generated during the fermentation of vegetable matter and the oxidation of paint oils. He could have been shown that white phosphorus can ignite itself.

Learning in science requires an adequate experience background. This applies equally well to the learning of facts and the understanding of principles. It applies to the development of skills as well as to the development of habits and attitudes.

Types of experiences. The baby's first experiences are with things that affect him directly—the touch of a nipple to his lips, a wet diaper against his skin, the sight of someone bending towards him. He relates these experiences to the immediate sensations of pleasure or discomfort they bring him.

Later he associates present experiences with past sensations—the sight of a bottle of milk with former pleasures of feeding, the sight of a dog with previous fear of an overly playful dog. He is using memory of past experiences in making associations with present experiences.

Finally, he begins to associate mental images that are produced by words or pictures with memories of past experiences. He hears the word "hot" and has a mental image of steaming food, which he relates

By working with soil themselves, these pupils are developing concepts they could never gain by reading, viewing films, or watching demonstrations. Most of their senses are coming into action to help them appreciate such qualities as odor, texture, structure, and moisture retention.

to a former feeling of pain. He sees a picture of an automobile that sets up an image of a real automobile; this he then relates to his former experiences with automobiles.

Science teaching makes use of all of these various types of experiences. Direct, firsthand experiences give information about such things as the color of flowers, the sounds of birds, the forces needed to lift different kinds of substances.

Recall of past experiences enables pupils to apply their learnings about levers to the behavior of the teeter-totter. Recall of experiences with house plants at home sets the stage for experiments with phototropisms.

Vicarious experiences help pupils visualize a hurricane from a written description, and the habitat of a polar bear from a picture. The completeness of the image depends, of course, upon the previous background of experiences the pupils can draw on for association of words and pictures.

Learning can be produced by means of all three types of experiences. However, each type has limitations as well as advantages. The effectiveness of each depends upon the care with which it is used.

Firsthand versus vicarious experiences. Firsthand experiences are basic experiences. A pupil may benefit from them without having a broad background of previous experiences or a certain degree of mental maturity. Pupils generally vary in their ability to interpret firsthand experiences but most of them are well able to receive the sensations involved.

Mr. Neuman was directing his physics class in a study of pulleys. The pupils rigged a "bosun's chair" from the framework of one of the playground swings. A single large pulley was fastened to the overhead support. A heavy rope passed over the pulley and ended in a large loop fitted with a board on which the pupils could take turns sitting.

First a pupil tried to pull up another pupil of about the same weight sitting in the chair. Then he sat in the chair and tried to pull himself up. The amazed comments of each pupil indicated how little any previous experiences had prepared them for this situation.

Mr. Neuman realized that he could not depend completely on the experience background of pupils for a study of pulleys. He knew that words, diagrams, and numbers could not substitute for the sensations involved in using muscles. So he took the time to set up a firsthand experience situation.

It is possible to build a complete science program on firsthand experiences, using experiments, certain types of demonstrations, and a great number of field trips. Such a program has many advantages. All pupils, no matter what their cultural or educational backgrounds, begin on an approximately even footing. Reading ability or the ability to interpret flat pictures is not needed. The teacher has assurance that each pupil makes approximately the same observations. The teacher knows the extent of the pupil background when he begins follow-up work.

There are two major limitations of the program that uses only firsthand experiences: (1) firsthand experiences are time consuming and restrict the amount of material that may be covered, and (2) the program deals only with materials of the immediate environment.

Such limitations may or may not be considered weaknesses depending upon the goals that have been established for a particular science course. If the goals can be met as well with local materials as with exotic materials, the second of the above limitations has no application. If the goals demand careful and intensive treatment of a few

situations rather than superficial treatment of many, the first limitation does not apply.

Vicarious experiences, used so preponderantly in our schools, need much more careful treatment than they usually receive.

A ninth grade class was viewing a film on automobile engines. The teacher, Mr. Dubois, had worked as an automobile mechanic and knew engines quite well. He considered the film to be an excellent one and decided to let it serve as the basis for the work of this unit.

Tom had twice helped his older brother rebuild a "jalopy." He found the film an excellent review of the structure of an automobile engine. The animated drawings summed up for him his knowledge of the events in a four-cycle engine.

Bill had never seen an automobile engine taken apart but he had a considerable interest in automobiles and knew the names and general functions of the parts he could see under the hood of a car. He had also seen a motor block displayed in an auto supply store so that he knew what cylinders and pistons look like. All the language used in the film was familiar to him and he learned a great deal from seeing it.

Marjorie had brothers who were always talking about automobiles. She had heard about the function of some of the parts. The film occasionally struck a responsive note, especially those sections dealing with the radiator, the carburetor, and lubrication.

Amy lived with a widowed mother who had no interest in things mechanical. If the family car did not operate properly, it was sent to the garage without any attempt to learn what was wrong with it. Amy had heard the word "radiator" but only in connection with a heating system. "Cylinder" meant little to her except a vague recollection of a type of solid once studied in mathematics. She had heard of valves in the heart but did not understand them. "Carburetor" was a word in another language.

Amy recognized the beginning sequences of the film in which an automobile drives up and stops. From the moment when the hood was lifted, however, she was in a completely strange world where sights and language were completely foreign. The animated drawings that meant so much to Tom and Bill, and that appealed so much to Mr. Dubois, were just lines in two dimensions to Amy.

About a quarter of the general science class profited greatly from the film and carried on a heated discussion about it. This convinced Mr. Dubois that the film was an excellent teaching device and that all pupils should benefit from it. He attributed the partial understandings of pupils like Marjorie to insufficient attention or lack of mental ability. As for Amy, he just shrugged his shoulders and muttered something about having to teach girls like that.

The effectiveness of vicarious experiences in teaching depends entirely upon the nature and extent of a pupil's background. A pupil who has moved to Florida after living several years in Vermont can readily understand references to a northern winter. Those of his classmates who have never left the South may understand little. Even pictures mean little to the latter because pictures can give only limited information—the color of the snow-covered landscape, the superficial appearance of snowdrifts, and the like. Such impressions as extreme cold, stinging wind, the texture of snow, and the changed sounds are difficult, if not impossible, to convey.

Means for communicating vicarious experiences are extremely limited. When speech is used, the listener must be able to interpret the words by forming images comparable to those in the mind of the speaker.

Mr. Lavery is describing to his chemistry class an experiment he has seen done with carbon dioxide. In his description he uses the term "generator." To Lucy this is a new word that has no significance to her. She is unable to produce any image. Charles knows the word only as applied to the electrical generator in a car. The image he produces is a confusing one. Phil has seen the term used in connection with a carbon dioxide generator during his reading. He produces an image similar to that in the mind of Mr. Lavery.

Science teachers commonly fail to consider the words they use in their classes. Accustomed to technical words themselves, they use these words without thinking. It is wise to be continually alert to the problems of vocabulary, remembering that pupils lack background, particularly in technical areas. Mr. Lavery could well have made a drawing of a gas generator and referred to experiments they had done in earlier years. Better yet, he could have displayed a gas generator and checked to see if his pupils understood its function.

Written language has the same limitations as spoken language plus the additional handicap of reading difficulty. Pupils must be able to recognize words and interpret sentences before they can begin to relate them to their experience backgrounds. Pupils vary greatly in reading ability. Many are seriously handicapped because they do not read well. These poor readers can profit from many experiences if the experiences do not involve written material.

All types of pictures have serious limitations. Two-dimensional pictures must be interpreted as three-dimensional images. Perspective may hinder proper interpretation. A close-up photograph of a small plant may make the plant appear as large as a tree in an adjoining photograph. Photographs give deliberately narrowed views, leaving

out much of the background and other surroundings for the purpose of focussing attention.

The majority of sensations cannot be transmitted from one person to another. Smell, taste, touch, and muscular sensation cannot be described. Sounds can be approximated with recordings and sound films but their accuracy depends upon the nature of the recording and playback equipment.

The limitations of vicarious experiences require that teachers use them with great care. A science program should not be based upon vicarious experiences alone. The extent to which they are used in combination with firsthand experiences depends on the backgrounds of the pupils For a group of pupils of fairly homogeneous background, who have travelled widely and developed many science understandings in earlier grades and who can read well and interpret pictures readily, a science program may include a large proportion of vicarious experiences. For a nearly homogeneous group made up of pupils with little travel experience, with a limited science background, and with poor reading skills, the program should consist largely of firsthand experiences. The needs of heterogeneous groups must be met by increased individualization of instruction.

Verbalization. Verbalization of learnings is an important part of education. Most of our culture is passed on to others through language. People are able to work together because they can share learning through words. Skill in verbalization is an important objective of our schools.

It should be realized, however, that verbalization is not the only outcome of education. Some learnings cannot be verbalized, and there can be verbalization without understanding.

Martha's father, a teacher himself, found Martha studying for a test in general science by repeating out loud, "The intensity of light varies inversely with the square of the distance." Curious as to why she should be working so hard on this seemingly simple concept, he began to question her. To his surprise, Martha had no idea of what the words meant. He set up a few experiments and discovered she already had the concept but had never related it to the statement in the text.

Many other pupils have memorized meaningless statements even as Martha was doing. Countless hundreds have undoubtedly repeated the names of the strokes of the four-cycle engine—"intake, compression, explosion, exhaust"—without the slightest comprehension of what actually goes on inside a gasoline engine. Even teachers commonly use terms without stopping to think what they mean.

Miss Ritchie placed a bottle of water on a sheet of paper. Then with a flourish to attract the attention of her general science class, she gave a quick jerk to the paper. The paper slid out from under the bottle, leaving the bottle unmoved.

The pupils considered this a most interesting trick, almost like magic. Up went several hands with the question "why?" Miss Ritchie explained briefly, "It's because of inertia." There were no more questions.

Had Miss Ritchie substituted the definition of inertia for the word itself, her explanation might have sounded something like this, "The bottle didn't move because things at rest tend to remain at rest." Her explanation would have seemed inadequate to both herself and her pupils. But her use of a strange and technical sounding word stifled further curiosity.

Science teachers tend to stress technical terms without good cause. Precise terminology has its value when science specialists communicate with each other. Most pupils, however, will never become science specialists and in consequence will not use the language. Since all commonplace things and all commonplace phenomena can be described in simple English, it is a waste of pupils' and teachers' time, as well as discouraging to some pupils, to insist upon mastery of a special science vocabulary.

In all science teaching it is better to work for understandings than for vocabulary. This means establishing an adequate experience background. Once this has been done, pupils can be encouraged to talk about their learnings. They may struggle in the search for words but their statements will represent their true understandings, not glib repetitions of the teacher or the text. Especially interested pupils will then quickly pick up and add to their vocabularies such technical words as they encounter in their reading.

As an example from the field of astronomy, pupils might be asked to recognize such words as Mars and Jupiter as the names of planets.

More important information can be treated on the recall level. To continue with the illustration used in the above paragraph, pupils might be asked to recall the names of the several planets. To do so would imply that the teacher considered this information of considerable value.

The highest level of learning is the mastery level which should be reserved for essential material. Much of the information necessary for health and safety practices justifies the time and energy needed to master it. But a study of the planets on the mastery level would require a degree of thoroughness unwarranted by the needs of the pupils.

There was a time when it was generally believed that mastery of material involved exercise of the mind, and that exercise strengthened the brain even as physical exercise strengthens the muscles. Pupils were asked to master all kinds of material, much of it useless, in order to develop the brain. This idea has been proven false but the doctrine has not been given up completely. One still finds traces of it in present-day teaching. "Pupils need homework assignments so they will learn how to study," many teachers claim.

Summarization. The extent and quality of science learnings can be greatly improved by proper summarization. As pupils receive new impressions they need time for and help in fitting the items of information they have gained into some general pattern.

Typically, the procedures used are lectures in which the teacher shows how the information gathered by the pupils fits into the pattern of formalized science, or else by discussion periods during which the pupils try to fit the information into the formal pattern outlined by teacher or text. Less used are discussion periods during which pupils decide upon their own patterns of organization.

Each spring Mrs. Woodward's biology classes studied a unit on flowers. The pupils took many field trips, examined flower structures in the laboratory, and tried experiments with flower reactions. Each pupil undertook at least one special study of flower growth, function or behavior.

Near the close of the unit, Mrs. Woodward set aside part of a period for the pupils to organize their notebooks and summarize their learnings. She permitted them to choose the form of organization by themselves.

Usually the pupils organized their material with the classification of plants in mind. Sometimes they chose structure, such as woody and non-woody plants, or flowers with and without petals. Once a class chose to organize its material according to the method of pollination involved. Mrs.

Woodward tried never to interfere, believing that the experience in developing a pattern for organizing learnings is a valuable one.

Notebooks are used extensively to help pupils summarize their learnings. Properly used, notebooks can be stimulating. Too often, however, pupils are forced to follow a teacher-set pattern that dulls initiative. As much as possible, notebooks should be the result of a pupil's independent work and should express his own thoughts and organization.

Purchased charts and models help summarize learnings. Textbooks are generally better for summarization than as a primary source of information. Slides and film strips dealing with materials already studied make excellent summaries. Many films are organized so as to serve best as summarization devices. Projects often make excellent summaries though they are rarely recognized and used as such.

During the study of electricity in the home a seventh grade class made a model house complete with wall lamps, wall outlets, table and floor lamps, switches, fuses, and a door bell. Long after the unit had ended pupils continued to work on the model.

The making of the model can be classified as a learning activity but the model itself served to summarize the learnings gained. Many other pupil projects—the making of charts, posters, and exhibits, for example—produce their own summarization devices. Other projects, such as plays, assembly programs, and radio programs summarize the learnings that are gained during their production.

Science lesson plans should provide a variety in the types of summary called for. Today, notebook diagrams may be used; tomorrow, a bit of textbook reading; the next day, a short discussion. Near the end of the unit a film may serve best. Each method makes its own specific contributions.

Review and drill. There is inevitably some forgetting during the period that follows learning, the extent depending upon the force of the original impressions and upon the strength of the associations formed. Forgetting also increases as time passes. Repetition of the original situation serves to renew the learning; several repetitions at intervals fix the learning firmly.

Review and drill are most important when dealing with learning on the mastery level. If information is considered important enough to be taught on this level, drill must be provided. For learning on the other levels occasional reviews are sufficient.

Reviews and drills are usually conducted solely in terms of verbalizations and drill is often considered as a question-response activity.

None of this need be so in the science program. It is better to depend more upon real materials than upon mental images for review and drill.

An excellent way to review a situation is to repeat it in actuality rather than in memory. A field trip may be repeated with the pupils pointing out the points that were considered the first time. Experiments and demonstrations may be repeated and reviewed in similar fashion.

Mrs. McMahon opened her seventh grade general science lesson by asking the pupils to list the items used in the demonstration she carried out the day before. As each item was listed, a pupil was delegated to select it from the materials on the demonstration table. Mrs. McMahon then asked the pupils to recall the steps used in the demonstration and delegated other pupils to carry them out. Finally she asked the pupils to give the possible conclusions from their observations.

Reviews of science materials may also be conducted by altering the original situation somewhat so that pupils must interpret the new situation in terms of the old.

During the study of atmospheric pressure, a seventh grade general science class saw the classic hard boiled egg trick in which a hard boiled egg is made to pop into a bottle as heated air in the bottle begins to contract. Two weeks later, during a review of the unit, the teacher demonstrated a similar trick in which a banana was made to peel itself as it was forced into the bottle. In explaining this second trick, pupils recalled what they had learned about the first one.

Drill may be carried on in similar fashion by varying a situation enough to keep interest high but not so much as to require special help with new learnings.

Mr. Mathewson's earth science class was studying the characteristics of soils, including pH and the minerals essential for plant growth. Mr. Mathewson suggested that the class set up a garden soil testing service for parents and neighbors. By the time the pupils had run tests on a large number of garden soils, they were thoroughly drilled in testing procedures and in the significance of the results.

TEACHING PRINCIPLES AND GENERALIZATIONS

Pupils are often asked to deal with certain broad statements of science, statements that sum up centuries of questioning, speculation and investigation. Some of the statements are easily proven in light of

present-day knowledge and may almost be considered as simple facts; for example, "Air is a mixture of gases." Other statements are too broad to have been completely proven and may need revision if new evidence contradicts them, but at present are generally accepted. One such statement is: "The cell is the structural and physiological unit of all life." Still other statements are theories with so much evidence supporting them that their theoretical nature is often forgotten; for example, "The planets revolve about the sun in fixed orbits." Finally, there are statements of theories that may never be capable of proof and that are often disputed; for example, "All life has evolved from simple forms."

Unlike the facts of science that can be learned through experiences, broad statements such as those above require the exercise of a good deal of thinking for understanding. Learning situations must be carefully organized to avoid empty verbalization, misunderstandings, and unthinking acceptance.

Inductive reasoning situations. The inductive method of developing generalizations has the special merit of showing pupils how scientific principles were first formulated. The pupils collect data, retain that which is pertinent to the problem, and formulate an inclusive statement from the data.

Miss Carpenter had shown her biology class how to make microscope slides of onion tissue in order to see the cells. One boy, who finished first, asked if he could try to find cells in other kinds of plants. Miss Carpenter was pleased with his interest and showed him how to make slides of the epidermis of leaves. Interest spread rapidly through the class and for the next few days the pupils examined almost a hundred different kinds of plants, including algae. They learned how to make thin sections with a razor blade and some used a hand microtome following a demonstration by Miss Carpenter.

One of the girls finally said, "It seems as though all plants are made of cells."

Her statement was immediately qualified by another girl, "But not all the same kind of cells."

A boy challenged the statement. "You can't say that a one-celled plant is made up of cells," he said. Several arguments centered about this point and were finally resolved in a new statement, "All plants are made up of one or more cells, usually of different kinds."

A final argument, initiated by one of the boys, restored the qualifying clause of the first statement, "It seems as though all plants are made up of one or more cells, usually of different kinds."

Miss Carpenter's class developed this particular generalization on the basis of a large number of observations, but even though no exceptions were found, the pupils recognized the limitations of their statement. Their minds were open to change in case contrary evidence was presented. It is probable that they would be critical of an equivalent statement discovered in their reading.

Had Miss Carpenter made the general statement as a preliminary to the observation of the onion cells, or had she referred them to their textbook beforehand, the pupils would probably have accepted the generalization without question. The pupils would never have had this valuable exercise in reasoning.

The procedure employed by Miss Carpenter requires adequate time for development; pupils must not be hurried through the reasoning process. Teachers who are interested in covering a good deal of material in a course often try to speed up the inductive reasoning process by presenting the evidence themselves. To develop the same generalization discussed above, they will use micro-projectors to show cells of different plants, they will display charts and models, and they will make use of films and slides. From the evidence presented they will "lead" the pupils into the general statement.

This seems at first like inductive reasoning on the part of the pupils but although the resulting generalization may be the same, the type of thinking is much different. The pupils have no choice of evidence, they cannot look for exceptions. The manner of presenting the evidence, prepared with the final statement in mind, determines the final statement. The complete procedure encourages passive acceptance rather than critical consideration.

Deductive reasoning. This manner of thinking is sometimes called "going from the known to the known," because it involves making logical inferences from general statements that have already been accepted. It is a method that is much used in science teaching.

Mr. Neuman's physics class had read as part of their assignment the paragraphs in their textbook that discussed Newton's laws of motion. Mr. Neuman used the beginning of the class period to clarify the thinking of the pupils on the statements in the book and then he illustrated the "laws" with some simple demonstrations.

A few days later, Mr. Neuman set up a model electric locomotive on an oval track. When he increased the speed of the locomotive beyond a certain value the locomotive "jumped the track." The pupils deduced from Newton's "laws" that the rails did not produce enough sidewards push on the wheels to make the locomotive go around the curves.

The pupils then experimented with banking the rails to provide more

sidewards thrust. With sufficient banking they were able to operate the locomotive at top speed.

Mr. Neuman's class exercised deductive reasoning in explaining the behavior of the locomotive. It is important to note, however, that they did not stop with the deduction. They experimented to check their statements.

The deductive reasoning process has two serious weaknesses. The generalization used as a basis for inferences may be completely or partially incorrect. The inferences deduced, while logical, may be incorrect. If pupils are not given opportunities to check their deductions, the errors are allowed to stand.

For a lesson on the composition of air, Mr. Potter chose a familiar demonstration from the seventh grade general science textbook. He floated a lighted candle on a block of wood in a tray of water. Then he inverted a glass cylinder and set it over the candle. Soon the candle went out and the water rose inside. Measurement showed that the water now occupied about a fifth of the original space in the cylinder.

The pupils had already been told that a fire needs oxygen to burn. They deduced that the candle used up the oxygen and the water went in to occupy the space. On the basis of their reasoning they wrote in their notebooks that air is about one-fifth oxygen.

Anyone versed in chemistry knows that the candle flame would go out long before the oxygen supply was exhausted and that one of the products, carbon dioxide, occupies as much space as the oxygen used to produce it. The amount of water entering the cylinder because of the depletion of the oxygen content would be small indeed.

Pupils cannot be expected to know these facts in the seventh grade and so their reasoning was logical in terms of what they did know (although they might have questioned the rise of the water in the cylinder after the flame went out instead of while the flame was burning). Mr. Potter's background was apparently limited and so his reasoning was likewise logical. The error which Mr. Potter made was in asking his pupils to use deductive reasoning in a situation which permitted no opportunities for checking.

Misuse of the deductive process gives rise to some odd forms of circular reasoning when dealing with theories. Pupils are often asked to deduce from the statement of the general molecular theory the behavior of molecules in ice as it melts. Of course the theory was developed to fit such phenomena as melting ice and so the reasoning takes pupils around in a circle. The fault lies in treating theories as facts to be accepted without understanding how they were developed.

The scientific method. Inductive and deductive reasoning as such do not require the testing of conclusions. Armchair philosophers, including some well-known scientists, have made valuable contributions and also interesting mistakes by depending upon these types of reasoning alone.

The scientific method of reasoning involves elements of both the inductive and deductive processes and demands in addition careful checking of conclusions. The method is not limited to science or to scientists, nor does it have a stereotyped pattern. All careful thinkers use it.

Tommy, one of the pupils in Miss Well's biology class, raised the question as to why there were so many flies in his attic windows on sunny days in winter. Miss Well encouraged class discussion, knowing that some unusual behavior patterns of insects could be investigated if the pupils were interested enough.

The class decided that the flies had come in at the beginning of cold weather and were attracted to the windows by the warm sunlight. When Miss Well asked, however, how the flies could find their way into the attic, no one could propose a satisfactory explanation.

The class decided upon some experiments with the flies if Tommy could catch enough for study. A few days later Tommy brought in the flies.

The first thing the pupils noticed was that the flies did not look like common houseflies. The wings overlapped giving them a somewhat dumpy appearance.

Some of the pupils used a cardboard carton to construct a room with cellophane windows on one side. Flies in the box swarmed to the windows when the air was warm but they clustered in a far corner when cold. Temperatures were taken and the critical point was found to be about 50° F.

The pupils then constructed another testing device by putting a partition across the center of a box. One room thus formed was given a cellophane window and the other was kept dark. A small opening in the partition connected the rooms. This time the flies went into the lighted room when temperatures were above 50° F and into the dark room when temperatures were below 50° F.

The pupils decided that flies try to get in dark places when cold and into light places when warm, or as a textbook would put it, the flies are positively phototropic above 50° F and negatively phototropic below 50° F. Tommy and some other pupils who lived in homes with open attics, checked temperatures and the presence or absence of flies in attic windows on several occasions.

Later the pupils tried other kinds of flies without such positive results.

They changed their conclusion to apply only to this one type of fly (the "cluster fly" *or* "buckwheat fly," Pollenia rudis).

Unconsciously, this class was making use of the scientific method. The pupils had a problem and they proposed some solutions. They gathered pertinent information, in this case by experiments, and arrived at a tentative conclusion that was tested by further observations. Continued testing caused them to modify the final statement to one that seemed satisfactory to everyone.

The scientific method of reasoning as a procedure in teaching has much to commend it. Although it demands adequate time for satisfactory development, the resulting learnings are sound. Pupils know the exact meaning of the general statement, they know its applications, and they know its limitations.

Although the scientific method of reasoning is little more than applied common sense, it is not something that can be taught by a lecture or a single illustration at the beginning of the year. The scientific method demands extensive practice in a wide variety of situations. It need not be formalized by listing it in sequential steps; indeed such formalization may interfere with the thinking of pupils. Pupils are generally intelligent enough to work out satisfactory procedures for each particular situation without reference to a formal list.

The teaching of theories. Theories are generalizations that have been formulated to explain a set of conditions. Some theories are widely accepted and some are in dispute. All theories are susceptible to modification and even to abandonment. The thinking person may accept a theory but he always does so with reservations. Many of the great contributions to science have been made by men who refused to accept blindly the theories prevailing at the time.

No part of the science program needs more careful treatment than the teaching of theories. It is all too easy to influence young minds into accepting theories as facts—either closing the minds permanently or making it difficult for the minds to be changed.

Pupils should be conscious of the theories dealt with in the science program. They should be shown why the theory was proposed, they should be given the data that was used in its formulation, and they should know the evidence that has accumulated in its support and any modifications that the theory has undergone. The limitations of the theory should be made clear.

Pupils trained to evaluate theories carefully have open minds. They can accept change. They realize that little is known in the field of

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science. They understand the challenge of science. They may be tomorrow's Kepplers and Darwins and Einsteins.

Unfortunately, teachers must do a good deal of sifting to isolate theories from facts Far too many authors and teachers ignore the distinction. Books commonly use the expression, "The Molecular Theory," without pointing out in the slightest how the accompanying information differs from factual material presented in other portions of the book.

A theory is recognizable because it cannot be proven by direct evidence. Indirect evidence may support a theory but cannot prove it. The Foucault pendulum does not prove that the earth rotates; the Foucault pendulum is instead explained by the theory of the earth's rotation. The motion of the Foucault pendulum is accepted as indirect evidence because its behavior cannot be accounted for satisfactorily in other ways. But indirect evidence is liable to misinterpretation; history is full of similar "proofs" that were later explained in contradictory ways. The last fifty years have been filled with startling alterations of theories.

A teacher may accept a theory himself on the basis of his broad experience background. No geologist questions the existence of the Pleistocene ice sheets. Indirect evidence that cannot be accounted for in any other way is so overwhelming that the theoretical nature of the explanation is ignored. But young people do not have the background to recognize the extent of the evidence. Instead of forcing them into passive acceptance, it is much better to present them with some of the evidence, give them the accepted explanation, and let them make their own decisions.

Teachers may sprinkle their statements liberally with qualifications such as, "If the air is actually made up of molecules . . . ," "If the earth actually does go around the sun . . . ," "If we accept the theory of evolution . . . ," "If there are genes in the chromosomes . . . ." Minds are then kept open.

Teachers may point out the assumptions on which theories are based. For instance, much work in astronomy is based on the assumption that light behaves in space as it does on the earth. Like the assumption that a straight line is the shortest distance between two points, this is an assumption that is rarely if ever questioned. But if the assumption were to be abandoned, a completely new set of theories would be possible.

The pupils in Mr. Kane's physics class had performed a number of demonstrations illustrating the expansion effects caused by heating. In each instance, the pupils applied the kinetic theory of molecules to their explanations and the pupils seemed to be well satisfied with the theory.

Then Mr. Kane performed a demonstration. He filled a flask with colored water and inserted a one-hole stopper containing a long glass tube. One of the pupils had used similar materials when explaining the thermometer. Instead of heating the flask, however, Mr. Kane set the flask in a jar of water, ice, and salt. At first the water went down in the tube and the pupils explained the decrease in volume by the lowered activity of the molecules. After a few minutes the water stopped going down in the tube and actually began to rise again. The pupils were astonished and could not explain the phenomenon.

Mr. Kane's special demonstration did not destroy the pupils' acceptance of the molecular theory but it quickly restored the theory to its true status. The pupils were beginning to treat the theory as fact and now they realized there were some possible qualifications to the general statement.

DEVELOPING SKILLS

Skills that may be developed in the science program range from the purely technical to the broadly general. Such skills as titration are of concern only to the science teacher. The academic skills, such as reading and oral expression, are the responsibility of all teachers. Skill in leadership, skill in adjusting to group work, and other general skills are among the desirable outcomes of the entire educational program.

Most technical skills are of value only to the specialist. The more general skills are of value to every pupil. For most pupils, skill with a handsaw is a more worthwhile outcome of the science program than is skill with a pipette. Skill with printing legibly is of more use than skill with a Wheatstone bridge. This does not imply that specialized science equipment has no place in the science program. Specialized equipment should be used whenever it will help pupils solve the problems they are working on. But pupils should develop skills with this equipment only as they have use for it, not because these technical skills have been made a part of the general objectives of the course.

Developing motor skills. Some of the special skills that can be developed in the science program require muscular coordination and are termed motor skills. Focussing a microscope and lighting a Bunsen burner may be classified as motor skills.

A few of the specialized skills of science appeal to pupils for

apparently no other reason than sheer enjoyment of manipulation. Pupils will work for hours with glass tubing—bending it, drawing it out into thin threads, blowing bubbles in it, and twisting it into fantastic shapes. They enjoy their first experiences with a microtome and with a stethoscope for similar reasons.

Generally, however, pupils learn motor skills because they need them to accomplish some end. Reference has already been made to the earth science class that set up a soil testing service. The pupils learned the skills of testing in order to test the soil from their parents' gardens. Pupils will also learn to solder in order to build a radio. They will learn to operate a chemical balance so that they can prepare diets in a nutrition experiment.

Motor skills are developed through a combination of observation, imitation, trial and error, and reflective thinking.

Sally wished to produce a musical tone by blowing over a bottle so that she could imitate a train whistle for a class play. Having only a vague idea of what to do, her first trials brought little success.

She asked a classmate to show her. He demonstrated the process and she watched him closely. Her next trials brought partial success but she could not be certain of producing a clear tone when she wanted to. She had to experiment with the position of the bottle each time.

Then she heard her science teacher speak of blowing across the mouth of the bottle. She had been thinking of blowing into the bottle. With this new concept in mind and a little more practice, she was able to blow a clear tone whenever she wished.

Analysis of her method of learning shows that Sally had a vague idea of what to do from previous observations but her knowledge was not enough to direct her trial-and-error learnings into fruitful channels. They did, however, give her enough background so that she profited from her classmate's demonstration. Imitation then gave direction to trial-and-error procedures.

Continued trial and error would probably have perfected her technique providing she did not become discouraged. But Sally reflected upon the statement of her teacher and gained a new concept that saved her much effort.

At first thought it seems that Sally could have learned much faster if she had observed and reflected first and made her trials after. However her lack of experience would have handicapped her in making observations and she would have had little basis for reflective thinking. It is possible that she would have learned even less rapidly.

Those motor skills that are considered sufficiently important to be

included as objectives for a science lesson can be taught with the same steps Sally used.

Mr. Seymour's chemistry class was about to make carbon dioxide generators for which they would need pieces of glass tubing bent at right angles. Mr. Seymour permitted the pupils to try to make the bends without help. The pupils had seen tubing being bent in demonstrations in earlier grades and had some idea of what to do. A few pupils produced badly flattened bends. Some produced only weird shapes.

Mr. Seymour now demonstrated the making of a good bend, explaining each step as he went along. On second trial, most of the pupils produced usable bends. A few were still unsuccessful and Mr. Seymour pointed out their mistakes. These pupils succeeded on the third trial.

Sometimes it is not desirable to permit free trial and error at the beginning of the learning process. No one would recommend that pupils be asked to use compound microscopes and prepared slides without direction. But it should not be assumed that preliminary demonstrations and explanations are immediately effective or that they can replace completely the demonstrations and explanations given near the end of the instructional period. Instruction in lighting a Bunsen burner might proceed as follows:

1. Teacher demonstrates and explains procedure.
2. Pupils go through the same steps without actually lighting the match.
3. Pupils now try to light their Bunsen burners.
4. One pupil demonstrates the process. Others criticize.
5. Pupils review reasons for various steps.
6. Pupils practice lighting burners once more.

The preliminary demonstration provides the basis for imitation. Then trial and error, limited at first to the steps without the use of a flame and later with a flame, acquaints the pupils with the materials and the procedures. The pupil demonstration with attendant criticism and discussion adds the reflective element.

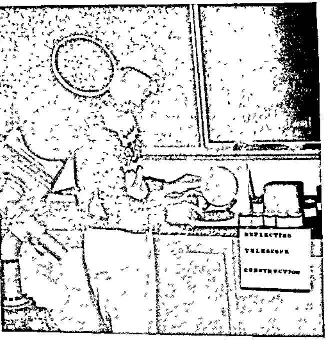
Instruction as outlined above is too formal to be used as a general practice in teaching motor skills. Only when introducing pupils to dangerous situations or to the use of delicate apparatus would a class be subjected to this formal treatment.

Motor skills are developed most easily through project work. The completion of the projects represents the objectives for the pupils. They master the skills in order to attain their objectives. And thus the teacher's general goals are attained.

Developing academic skills. Pupils coming into the secondary school have already had instruction in the basic academic skills; the science

teacher need not know the procedures used in introducing these skills. Even in the case of seriously retarded pupils he should leave remedial measures to specialists.

What young people need at this level is as much practice as possible on a level suited to their immediate abilities, difficult enough to be challenging, but not so difficult as to be discouraging. The science teacher needs to know how to provide such practice as part of his regular program.



Adolescents commonly devote an amazing amount of time and energy to special interests. When this energy is channeled into constructive activities, their achievements can be tremendous. Their learnings go far beyond any they may gain in the classroom, both in quantity and in depth. Moreover, these learnings persist longer and with greater clarity than those obtained from ordinary classroom activities.

The broad range of the science program permits pupils to work in areas of special interests. Some like to write and produce plays, radio programs and assembly programs. Others enjoy preparing charts or contributing science notes to the school and local newspapers. Most pupils like to do experiments, many of which involve mathematics and written reports. Many like to present demonstrations, make dioramas, or take field trips and report on their observations. Some enjoy using books to find answers to questions they raise about their findings.

One of the most important things for the science teacher to remember when encouraging the use of academic skills is to maintain a positive attitude toward the achievements of his pupils. A written report should be evaluated for what it says, a chart for its organization, a diorama for its accuracy. If the contributions of pupils are subjected to harsh criticism for minor flaws the pupils quickly become discouraged and stop trying. The teacher must work for much practice and gradual improvement rather than a little practice with immediate improvement.

Developing general skills. No one expects a young person to become a piano player without practice. No one should expect a young person to learn to cooperate with others, or to assume leadership, or to take responsibility for his own behavior unless he has opportunities for practice. In the past, the direction of this type of training has gone by default to the relatively few volunteer agencies that reach boys and girls. More recently, the extracurricular program of secondary schools has been organized to meet the obligation.

The general skills are too important to be ignored through the several hours of class work each day. They are important enough to be in the minds of teachers at all times and to be considered during all planning. The teacher who concentrates solely upon subject matter neglects the general growth of his pupils.

DEVELOPING ATTITUDES

The attitudes of young people determine their responses to every situation, affecting their behavior, influencing their observations, and coloring their thinking. A strongly positive attitude permits growth; a negative attitude hinders growth. A critical attitude aids in making wise decisions; a tolerant attitude helps in adjusting to social relationships.

Boys and girls entering the secondary school do not represent fresh white pages on which teachers can write. Each pupil has had countless experiences that have produced a wide range of attitudes. Rarely will a science teacher be able to develop in a pupil a completely new attitude. He must expect instead to work with existing attitudes—strengthening some, altering others, and trying to replace still others.

Attitudes involve emotions and in consequence may be difficult for a teacher to deal with, especially when he is trying to alter an attitude that reflects home or group values. All highly emotional situations must be treated with care lest highly undesirable attitudes develop.

The importance of positive attitudes. The novel "Blackboard Jungle" presents a heartbreaking picture of an idealistic young teacher trying to break through the negative attitudes built up by a group of New York City boys who had been subjected to years of continued failure in a large, impersonal school system.[2] Sometimes he seemed to make small gains but a day later he would find himself back where he started. His accomplishments for a year's work were insignificant.

Positive attitudes are essential if pupils are to gain from schooling. They must enjoy science work. They must have self-respect as well as admiration for those who succeed, and they must like the teacher. These attitudes are the direct outcome of success. Pupils will participate with increased frequency in activities in which they find increasing success. They withdraw from activities in which they encounter repeated failures.

Personal pride is an important factor in developing positive attitudes. When a pupil takes pride in his accomplishments, whether these be high grades or tangible results, he is able to grow. But if a teacher cannot help a pupil do something that makes him proud of himself, he will fail in his objectives.

Sources of attitudes. Allport suggests that there are four primary sources for attitudes:

1. *General approach or withdrawal tendencies.* A pupil may develop a strong liking for the study of electricity because he is able to manipulate materials, a type of behavior he enjoys. Another pupil may develop a distaste for zoology because he does not like to handle dead things.
2. *Other people.* Most young people who fear snakes have adopted this attitude ready-made from others.
3. *A single dramatic experience.* Intense embarrassment resulting from an accident during a demonstration may prejudice a pupil against participating in demonstrations again.
4. *The integration of numerous specific responses.* A succession of minor rebuffs by a teacher may lead to a strong dislike for the teacher. Discovery of errors in numerous textbooks may make a pupil critical of textbooks.[3]

Importance of early impressions. Initial experiences in an area produce the most firmly entrenched attitudes. Thus attitudes developed early in life from the attitudes of parents color the thinking of people

[2] Hunter, Evans, *The Blackboard Jungle,* Simon and Schuster, New York, 1954.

[3] From Allport, Gordon W., "Attitudes," *Handbook of Social Psychology,* Carl Murchison, ed., Clark University Press, Worcester, Mass., 1935.

the remainder of their lives. Prejudices developed against races, religions, and nationalities during the early years of childhood are seldom completely wiped out no matter what later experiences an individual has.

The first day in a science program may have more influence on the attitude of pupils towards the course than days of patient effort later in the year. Pupils usually approach a science course with a feeling of expectancy unless they have been badly conditioned by the reports of parents or other pupils. The first day can be so organized that pupils leave at the end of the period with a feeling of great satisfaction and enthusiasm. When possible, it is wise to begin with a unit that permits a good deal of pupil manipulation.

Miss Carl liked to start her seventh grade general science classes with leaf printing. She provided a supply of wilted leaves, glass plates, tubes of mimeograph ink, rollers, and mimeograph paper. She demonstrated the process and then set the pupils at work.

Pupils who had previous experience with this or some other process of leaf printing were asked to help the others or to prepare demonstrations for later use.

Toward the end of the period Miss Carl brought the work to a close and encouraged the pupils to discuss what they could do with the prints. Usually it was decided to make collections of the prints of all the trees in the neighborhood. Field trips and independent work were planned and the unit on plants of the environment was off to a good start.

Miss Carl's approach sent the majority of her pupils away from the first period with high enthusiasm for what was to come. One can imagine that a large percentage of them would come back the second day with a handful of leaves collected out of school, an indication that they were already thinking about their science program.

Many teachers believe that the first day or so should be spent in previewing the year's work. If this is done, great care must be used. The teacher already has in mind a view of what will be done and he feels enthusiasm for the prospect. But the pupils have no such vision and the preview is apt to be dull and uninspiring.

Some teachers like to use the first day to inventory pupil interests in order to build a program on the interests. Sometimes they ask the pupils to select the material to be studied. Again, this is a process that requires careful treatment. Some pupils have no background on which to base ideas of what should be in a science program. Some are retiring and do not participate in discussions. Some dominate discussions without contributing anything. It is common for pupils to leave these sessions with a feeling of futility.

Influence of a dramatic experience. Dramatic experiences produce strong emotions and lasting attitudes. These tend in the main to be negative attitudes, against certain situations or against certain people. This method of developing attitudes should be used rarely if at all by science teachers.

In the interests of safety, it is sometimes felt that a single dramatic situation will so impress the need for caution on pupils that they will avoid dangerous practices. The idea is a good one but unfortunately one has little control over the direction that such attitude development follows.

Mr. Finch wanted to impress upon his pupils in chemistry that they must have no open flames around their hydrogen generators. He filled a rubber balloon with hydrogen and held it near the ceiling by means of a thread. He brought near it a lighted match on the end of a long stick. The resulting explosion shook the building.

His pupils were deeply impressed. He could hardly get the girls to ignite the hydrogen they collected in bottles. Some of the boys began laying plans for filling a bigger balloon and producing a bigger and better explosion.

Influence of example. In a previous section there was a discussion of the teaching of theories. It was pointed out that teachers should treat theories with care, pointing out how the theories were developed, what the basic assumptions are, and what the limitations are. In so doing, the science teacher is setting an example of the scientific attitude. If a teacher is consistent in his attitude, his example can have a favorable influence on his pupils.

If a teacher wants his pupils to have a critical attitude in the constructive sense, he must be critical himself of his own statements, of books and films, and of the pupils' work. If he wants pupils to be tolerant he must always be tolerant himself. It is possible that the influence of all great teachers derives from the attitudes they themselves possess and pass on to others. Certainly anyone can pass on information, but only the person with strong, positive attitudes can influence the thinking of those he works with.

Suggested activities

1. Select a small segment of a course of study and list the learnings that are expected. Classify these as: (1) learnings for which pupils have adequate background to gain by lecture; (2) learnings which pupils can gain from reading; (3) learnings which pupils can gain from pictures; (4) learnings for which pupils need firsthand experiences.

THE SCIENCE PROGRAM IN OUR SCHOOLS

chapter 4

Science education in the United States has developed in somewhat haphazard fashion, as various pressures have been applied and as different states and communities have responded in their own ways. Until one knows the background of this development, there is much in the program that seems irrational. With an understanding of the background, the teacher is better able to fit himself into the total picture and to recognize those aspects of the program that are valuable and those that might well be changed.

PATTERNS OF SCIENCE PROGRAMS

Over the country there are several different patterns for the public schools. In an 8-4 system, there are eight years in the elementary school and four in the secondary school. In a 6-6 system, there are six in each of the two schools. In a 6-3-3 system there are six years in the elementary school, three in the early secondary or junior high school, and three years in the upper secondary or senior high school. Each system has its own pattern of science courses. Some of the more common patterns are shown in figure 2.

Pattern A on the chart represents a program that was widespread before general science was developed. The ninth grade course was called elementary biology, or just biology, and was required of all pupils. Pattern B represents a similar program with electives only. Both patterns can be found today but are not common. After general science was introduced, Patterns A and B were modified by making

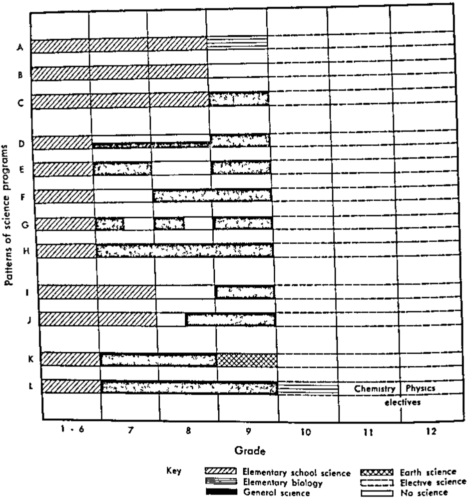


FIGURE 2. *Patterns of science programs in the United States.*

general science a required course in the ninth year, shown as C. This is the usual pattern found today in 8-4 systems.

Pattern D conforms to the recommendations given in the Thirty-first Yearbook of the National Society for the Study of Education.[1] General science is taught three days a week in the seventh and eighth grades and five days a week in the ninth grade. Patterns E, F, and G are modifications that provide about the same amount of time for general science but permit scheduling the subject five days a week. Under Pattern G, general science is taught for only one term in both the seventh and eighth grades. The majority of schools organized on the 6-3-3 plan or the 6-6 plan use one or another of these patterns.

[1] *A Program for the Teaching of Science*, Part I, Thirty-first Yearbook of the National Society for the Study of Education, Public School Publishing Co., Bloomington, Ill., 1932.

helps pupils approach problems intelligently and gives them confidence in their ability. The elementary science program can provide them with a rich and well-rounded background of experiences. These are the products upon which secondary school science teachers can capitalize.

Science in the elementary school has been developing rapidly in recent years. Today, many pupils enter the secondary school with an extensive knowledge, not only of the facts of science, but of the methods of science. In addition they are accustomed to working alone or in groups, to planning their own procedures, and to presenting their findings to others.

Courses of study in elementary science are generally well balanced, containing material from most of the traditional areas of science—the biological, physical, and geological areas. They emphasize health, safety and conservation.

Elementary science, like all other divisions of the science program, varies in its effectiveness from school to school and from teacher to teacher. The variation in the elementary school may be somewhat greater because of the greater variation in the backgrounds and interests of the teachers. Some elementary teachers like to teach science and

have adequate backgrounds for it. Some teachers try to teach science but feel inadequate for the task. Others dislike science and teach little or none.

Schools differ, too, in the help they give their teachers. Some systems provide in-service training workshops and some provide special science consultants. Some provide a wealth of materials, freedom for field trips and other special activities, and recognition for the accomplishments of both pupils and teachers. Other systems give no help.

Variation in the quality of the elementary school program need not hinder the secondary school science teacher. He may ask the pupils who have special interests and backgrounds to present demonstrations, to carry out projects, and to help the others. He should be grateful for the enthusiasm that these pupils bring to him from their earlier program.

GENERAL SCIENCE

General science occupies a critical position in the secondary school curriculum. It is required of nearly all pupils. It is the first experience most pupils have with science as a special subject. And it may be the only science course that some pupils will take during their high school experience.

General science determines the attitude that many pupils develop towards science. When the course is exciting, satisfying and rewarding, boys and girls look forward to further science study. But when the course is poorly taught, pupils are apt to look to other fields for satisfaction. General science deserves the best teaching and the best facilities that can be provided.

General science is generally offered as a one-year course in the ninth grade, or as a two-year or three-year sequence in the seventh, eighth and ninth grades. An increasing number of school systems are adopting the two- or three-year sequence according to a recent report.[2] This report further states that the amount of class time given to general science is also increasing.

General science, as its name implies, has a broad scope and can be applied to a broad range of interests. It was never intended, however, that general science be made up of a smattering of the specialized sciences. It has its own body of subject matter that is chosen to meet the needs of the pupils who take it. Nor should a general science course touch upon every aspect of science. To do so would result in superficiality and could only cause feelings of frustration and dissatisfaction

[2] Smith, Keith, "Trends in Junior High School Science," *The Science Teacher*, March, 1956.

on the part of the pupils. General science is "general" only in that it is free of the traditional boundaries of the various areas of science.

General science is a relative late-comer into the secondary school curriculum. Experimentation with this subject began about the beginning of the century Widespread adoptions occurred during the period from 1915 to 1930.[3] By 1932 it was a regular part of the ninth grade curriculum in a substantial majority of the schools throughout the country. The development of the junior high schools during the same period encouraged the extension of general science into the seventh and eighth grades.

General science was introduced into the curriculum as part of a general effort to humanize the secondary school curriculum. The courses offered at the beginning of the century were far from suitable for the great majority of pupils entering high school. After a brief taste of the offerings, boys and girls were leaving school in large numbers. Hunter states that during 1908 in New York City 43 percent of the enrolled pupils had left by the end of the ninth year and 70 percent had left by the end of the tenth year.[4] The formal science courses of the time were in part responsible for the high drop-out rate.

Educators recognized the need for a different type of science course. They recognized the need for a course designed for pupils who would elect no more science, a course designed to help them understand and use the things of science commonly encountered in daily life. These educators also recognized the need for a course in science for pupils who would continue the study of science, a course that would permit exploration of interests and abilities and the building of a background of experiences.

Early courses of study and textbooks show considerable diversity in content and approach. Some teachers emphasized the exploratory function of general science, presenting samplings of the various specialized sciences loosely tied together. This type of course was of little value to pupils who would not study science further.

Other teachers emphasized the preparatory function of general science, building the course from the introductory phases of physics, chemistry, biology, physiography, and astronomy. They developed specialized vocabularies, skills with formulas, and basic information. Such a general science course was of even less value to pupils who would not enter scientific fields.

A large number of teachers emphasized the practical applications of

[3] *A Half Century of Science and Mathematics Teaching*, Central Association of Science and Mathematics Teachers, Oak Park, Ill., 1950.
[4] Hunter, G. W., *Science Teaching at Junior and Senior High School Levels*, American Book, New York, 1934.

science. They taught their pupils how to repair leaky faucets, how to repair lamp cords, and how to choose a proper diet. Pupils probably benefited from this treatment, but formally trained science teachers considered the courses to be a "hodge-podge" of little value.

Gradually there grew a feeling that general science needed broader goals. A study made in 1930 showed that science teachers were thinking in terms of the development of interests, desirable attitudes, and certain general skills.[5] Some were still thinking of the preparatory function of general science, but most were thinking in terms of giving an understanding and an interest in the environment. It is significant that few considered general science to have any responsibilities towards helping boys and girls adjust to their social groups, find security, or explore their capabilities. General science teachers were thinking as science specialists, not as educators.

It is unfortunate that general science was so little influenced by the changed thinking in the elementary school during the twenties. Had general science teachers been encouraged to think in terms of the overall development of each of their pupils, many later mistakes could have been avoided and the potentialities of general science could have been exploited much more fully.

It is also unfortunate that general science was not more directly affected by the nature study movement of the early 1900's. Nature study has a very sensible and human approach to the study of science. "Study things—not ideas" and "Learn by doing" are among the precepts that govern the nature study program. Pupils respond much more eagerly to the procedures of nature study than to the procedures of formalized science that prevailed in general science whenever subject matter specialists took over the program.

In 1932 there appeared the yearbook of the National Society for the Study of Education—a publication that was to have a strong effect on general science.[6] This yearbook proposed for the twelve years of public schooling a science program based on the major concepts of science. The yearbook listed thirty-eight major generalizations to be used as objectives for science instruction throughout the entire sequence of elementary, junior high, and senior high school science.

Building a science program around the major generalizations of science makes possible a highly organized, and well-integrated outline which is extremely logical from the adult point of view. This type of

[5] Hunter, G. W., and Knapp, R. A., "Science Objectives at the Junior and Senior High School Level," *Science Education*, October, 1932.

[6] *A Program for the Teaching of Science*, Part I, Thirty-first yearbook of the National Society for the Study of Education, Public School Publishing Co., Bloomington, Ill., 1932.

presentation appeals to administrators who like clearly defined objectives and well-developed sequences. The proposals of the yearbook were quickly given widespread approval and have dominated the thinking of science educators for the last two decades.

There have been objections to the proposals outlined in the thirty-first yearbook from the beginning. Hunter in 1932 said, "These generalizations completely leave out applications of science to the lives of children, no reference to health or citizenship objectives as such being found Intellectual objectives hold complete domination over practical ones."[7]

Despite the objections of Dr. Hunter and others, general science continues to be dominated by intellectual objectives. Courses of study and textbooks emphasize generalizations rather than discovery. Demonstrations and experiments are used to "prove" that what the books and teachers say is true rather than to permit problem-solving situations. The potentialities of the immediate environment for developing the emotional and social side of pupils are neglected in most general science courses.

General science has another handicap, which is a result of the times—a superfluity of material. As each major development of science has been brought to the attention of the public—television, jet planes, nuclear reactors,—teachers and authors of texts have hastened to add them to the curriculum without considering the suitability of the added material. As a consequence, courses of study and textbooks are filled with information that is "up-to-date," but which has little or no function in meeting the general objectives of education.

The picture that general science presents today is one of a course that is not realizing all its potentialities. A symptom of this failing is a low interest in senior high school sciences, the diversion of capable students into other than science fields, and the shortage of scientific personnel in industry and governmental agencies. Some of the failures of general science are due to circumstances beyond the control of individual teachers. Large classes, heavy class loads, and inadequate facilities are the inevitable result of a rapidly expanding school population. But there are other failures that result from the selection of unsatisfactory objectives. These are failures that can and should be remedied quickly.

The challenge is obvious. General science is a course of great importance in the secondary school curriculum. In terms of influence on a large number of boys and girls, general science should be considered the most important of all the secondary school sciences.

[7] Hunter, G. W., *Science Teaching at the Junior and Senior High School Levels.*

THE ELECTIVE SCIENCES

Since about 1920, the choice of elective sciences in most high schools has narrowed to three: physics, chemistry, and biology. Occasionally a school offers one or more other electives in science because of the facilities or because of the interest of an individual teacher. But the numbers of pupils enrolled in these courses is not large. Table 7 gives the enrollment in the more common science electives in 1948-49. To meet special needs special courses have been set up on a local basis.

Subject	*One-semester course*	*Full-year course*
Seventh-grade general science	132,210	341,691
Eighth-grade general science	134,474	477,661
Ninth-grade general science	27,752	1,046,182
Advanced general science	1,820	46,226
Biology	3,395	986,361
Advanced biology	615	2,961
Botany	1,157	6,513
Conservation	1,846	1,700
Zoology	1,431	3,620
Physiology	14,847	38,745
Physics	1,284	277,550
Physical science	291	6,715
Fundamentals of electricity	1,019	1,398
Radio, including electronics	698	2,550
Aeronautics	1,827	13,132
Chemistry	1,531	405,131
Advanced chemistry	337	1,520
Earth science	4,828	15,747
Related science	2,118	5,214

TABLE 7. *Secondary school enrollment in science courses offered in 15 or more states, 1948-49.* (Data from Office of Education, *Biennial Survey of Education in the United States,* Chapter 5, "Offerings and Enrollments in High School Subjects, 1948-49, U. S. Government Printing Office, Washington, 1951.)

Enrollments in all elective sciences increased greatly during the first half of the century. Physics tripled and chemistry increased twelve-fold. But even as these enrollments mounted, the general school population increased too. Thus, on a percentage basis, chemistry has seemed to hold its own, while physics has seemed to drop off seriously. Table 8 gives these percentages. The picture is not so bad as the percentages seem to indicate.

Year	*Biology*	*Chemistry*	*Physics*
1890	—	10.1%	22.8%
1900	—	7.7	19.0
1910	1.1%	6.9	14.6
1915	6.9	7.4	14.2
1922	8.8	7.4	8.9
1928	13.6	7.1	6.8
1934	14.6	7.6	6.3
1949	18.4	7.6	5.4
1955*	19.6	7.3	4.6

TABLE 8. *The percent of pupils enrolled in certain courses in science in public high schools.* * *Estimate based on a sample of public secondary day schools.* (From Brown, K. E., "National Enrollments in High School Science," *The Science Teacher*, March, 1956.)

In table 8, the percentages for any one year are based upon the total enrollment in the upper four grades for that year. Obviously, no ninth grade pupils would have elected physics or chemistry during that year, and few would have elected biology. Yet their numbers swell the base figure and decrease the resulting percentages. By the same reasoning, the percentages for physics and chemistry are still further reduced because few tenth grade pupils are permitted to elect these subjects.

Brown attempts to give a more realistic picture of the present situation by assuming that biology is elected only by pupils in the tenth grade, chemistry, by pupils in the eleventh grade, and physics, by pupils in the twelfth grade. He then calculates percentages in terms of the pupils eligible to elect these courses. His results are given in table 9. His figures favor biology over chemistry and chemistry slightly over physics.

Subject	*Actual enrollment*	*Percent*
Biology	1,293,900	72.6% of tenth year enrollment
Chemistry	482,700	31.9% of eleventh year enrollment
Physics	302,800	23.5% of twelfth year enrollment

TABLE 9. *Approximate percentages of eligible pupils enrolled in senior high school sciences in 1954.* (From Brown, K. E., *op. cit.*)

The charge that high schools are not guiding enough young people into scientific work cannot be refuted. Perhaps the fault lies in the nature of the senior high school courses. Certainly if most of the

302,800 pupils who elected physics in 1954 were to choose careers in science, some as engineers, some as physicists, some as technicians, the effect would be appreciable. And if a substantial majority of the million or so who elect biology yearly were stimulated to continue their training in science the supply would begin to overtake the demand.

High school sciences tend to be influenced strongly by college and university science programs. At one time high school science was completely dominated by colleges and universities, even the content being dictated through the College Board Examinations. The direct influence is not so strong today, but teachers are apt to think in terms of preparing boys and girls for the college sciences. In 1930, high school teachers listed college preparation as their most important objective.[8] It would be interesting to know how many today set up the same objective, consciously or unconsciously.

The method and content of college science courses is rarely well suited to the needs and interests of secondary school pupils. Attempts to prepare for such courses by drill on vocabulary, emphasis on memorized formulas, laboratory work devoted to gaining skill with college laboratory apparatus, and insistence on verbalization of principles rarely produce stimulating high school courses.

High school pupils need entirely different types of courses. They need courses that satisfy their immediate needs and that enable them to explore their own interests and abilities. They need courses that show them the great challenge of work in science.

High school science courses should give only minor considerations to college needs. Boys and girls who have developed strong interests in science, who have rich backgrounds of science experiences, and who have confidence in their abilities will succeed in the college sciences.

Biology. Biology is by far the most popular of the elective sciences. The figures of Brown[9] indicate that a substantial majority of high school pupils elect biology. The rapidly increasing percentages during the last fifty years, even as school populations have risen at a startling rate, attest to its appeal to young people.

One can only speculate as to why the popularity of biology has increased so much more than that of physics and chemistry. Perhaps it is because biology teachers have been less hampered by tradition and by the influence of college science. Perhaps pupils find the subject matter more meaningful and more easily applied to themselves. Per-

[8] Hunter, G. W., and Knapp, R. A., "Science Objectives at the Junior and Senior High School Level," *Science Education*, October, 1932.

[9] Brown, K. E., "National Enrollments in High School Science," *The Science Teacher*, March, 1956.

haps biology lends itself successfully to the teaching of classes containing pupils with a wide range of abilities.

High school biology today bears little resemblance to its forebears of the nineteenth century. Previous to 1900, schools offered separate courses in botany and zoology, and later in human physiology. These courses emphasized classification and morphology. Laboratory work was primarily concerned with detailed studies of structural types. Teaching was strongly influenced by the doctrine of formal discipline which held that the mind could be trained by special exercises.

The closing years of the century saw certain significant developments. Teachers began using experiments in physiology in place of studies of structure alone. The rising nature study movement, which emphasized the study of living things in their natural environment, stimulated field work and the study of interrelationships. These two factors greatly changed the pattern of biology courses.

In 1900 the move to unify the several phases of biology into a single course gained momentum. At first the resulting courses consisted of distinct sections devoted to zoology, botany and human physiology, respectively. In these courses, type studies were often used, with perhaps an apple tree to illustrate a woody plant and a grasshopper to illustrate an insect. Field trips were taken to see these organisms in their natural environment. Laboratory exercises gave detailed studies of their structure and experiments with their physiology.

Such courses persisted into the 1920's. In many ways they were excellent courses, interesting and effective in meeting the goals of science education. Unfortunately, it was all too easy for the type studies to become formalized into the pattern of college sciences. And the lack of integration between the separate sections of the course disturbed many educators.

The Thirty-first Yearbook of the National Society for the Study of Education had as great an impact on secondary school biology as it did upon general science. A number of the thirty-eight major generalizations of science listed in the Thirty-first Yearbook as objectives for a twelve year science program were derived from the field of biology.

Courses built upon these generalizations differed completely from earlier biology courses. They were well integrated. Plant and animal cells were studied at the same time, to make comparisons easier. All forms of reproduction were combined into one unit. Such biology courses were systematic, highly logical, and generally appealing to secondary school science teachers. Today most high school biology courses and most textbooks are organized on this plan although in recent years modifications are increasing.

Excellent as a course based on major generalizations may appear on superficial examination, serious defects show up in actual use. The use of major generalizations as goals to be attained quite effectively eliminates the discovery approach to science. No pupil can possibly discover enough in one year to arrive at even one major generalization. Experiments, demonstrations, and field work must be used chiefly as illustrations of the ways generalizations apply. Indeed, laboratory and field work can be minimized or even eliminated in such a course because books, films, and slides are able to present applications of generalizations much more quickly and effectively and without the problem of introducing confusing exceptions.

Much that was good in earlier biology courses was lost in using major generalizations as objectives. Type studies were abandoned, although type studies give the best concepts of an organism as a whole, since an organism is more than the sum of its parts or the sum of its processes. Lost too has been the emphasis upon the place of living things in their natural environment, a loss that cannot be replaced by a single unit on the principles of ecology.

On the whole, the recommendations of the Thirty-first Yearbook have improved high school biology greatly by providing an effective organization. Major generalizations are excellent centers about which to build a program. But the discovery approach to biology requires more specific objectives.

Physics. Ever since World War II, the critical shortage of engineers and physicists has brought dismayed looks at the enrollments in high school physics. Certainly the statistics given in table 8 are not flattering. One cause for such low percentages in recent years has already been discussed as a matter of arithmetic, namely, the choice of a base that automatically keeps percentages low. Table 9 indicates that actually about one pupil in five elects physics during his senior year.

The cause for declining percentages since 1900 is in part the result of the increased holding power of the high school. In 1900, pupils without interest or ability in physics usually left school early and thus a high proportion of those remaining were in physics classes. Today, the base on which percentages are based is swelled by large numbers of pupils who would not have stayed in school a half century ago.

Using a different base for percentages gives an entirely different picture. Enrollments in physics have tripled since 1900. They have kept pace with the general population growth. In other words, secondary school physics seems to be attracting about the same proportion of boys and girls with science aptitudes as formerly. But all such discussion must not obscure the fact that very few physicists and engineers

are being trained each year. High school physics should attract many more boys and girls than it does and it should guide a substantial number of them into scientific careers.

The relative unpopularity of physics is not due to the nature of the subject itself. No area has more applications to everyday life. No subject deals with more exciting devices. The fault lies in the goals that are set up by teachers.

Marcus, in the preface to his high school text, points out that the popularity of physics has not been improved by simplifying the content or by squeezing out the mathematics. He identifies the offending factor thus: "For the great majority of high school students who are not going to college, and even for most who do, a high school course that is a preparation for a college physics course is meaningless." [10]

But despite the efforts of Marcus and others, the college preparatory function of high school physics continues to dominate the thinking of physics teachers. As Hunter said at a much earlier date, "Physics as a college entrance subject has been so firmly entrenched that teachers have had little opportunity to do more than follow rather definite courses of study based on factual material and laws which college professors deemed necessary as a basis for further achievements in college." [11]

The following are some of the causes for the inadequacy of secondary school physics:

1. Emphasis upon principles and "laws" rather than upon the concrete things of the environment.
2. Insistence upon memorization of formulas and standardized ways of solving problems.
3. Excessive use of mathematical exercises in order to develop skills with formal science problems.
4. Employment of stereotyped laboratory exercises and materials of the type used in formal college classes.
5. Failure to provide for individual differences.
6. Inability to stimulate original thinking.
7. Refusal to accept responsibility for social and emotional growth of pupils.

If physics teachers would discard the artificial standards established long ago by the colleges, reorganization of physics into a vital and worthwhile subject would not be difficult. A physics course can be set up to deal with the things of the environment. To quote Marcus again:

[10] Marcus, A., *Physics for Modern Times*, Prentice-Hall, Englewood Cliffs, N. J., 1952.

[11] Hunter, G. W., *Science Teaching at Junior and Senior High School Levels*, American Book, New York, 1932.

> For most students this means an understanding of the concrete objects of their environment, not the abstractions. It is not the various physical theories, laws and principles, but rather the automobile, the airplane, the alternating-current motor, the radio receiver, the television set, the atomic reactor, that constitute the physical environment of the students.[12]

A physics course designed for high school boys and girls should be flexible enough to permit pupils to follow up their special interests and utilize their various talents. It should be based upon the discovery approach and the problem solving technique. Laboratory work should be devoted more to experimentation and less to "verification" exercises. Much class time should be spent on individual and group project work.

Chemistry. Chemistry has fared better than physics in popularity during the past few decades. It has continued to attract about the same percentage of pupils from the general school population for fifty years. It has broadened its appeal to the type of pupil who once left school long before graduation.

As in the case of physics, however, chemistry is failing to direct an adequate number of young people into scientific vocations. Pupils take the high school science course and then turn to other fields for their life work.

The criticisms that have been leveled at physics apply equally well to chemistry. The usual chemistry course is concerned almost completely with abstractions. Pupils must memorize endless laws, principles, minor facts, symbols and formulas and equations. From the very beginning they are drilled in chemical shorthand until they assume that formulas and equations *are* chemistry, not merely a simplified way of expressing what is known about chemistry.

Much laboratory work in chemistry consists of sets of exercises. Some of these are designed to teach pupils the use of chemical apparatus and procedures. Others are designed to illustrate generalizations made in books and lectures. Rarely do the pupils carry out true experiments in which they are trying to find the answers to real problems.

It is interesting that with these serious faults chemistry has been able to maintain its enrollments. Anyone who knows junior high school pupils, however, may suspect the answer. To boys and girls of the early secondary school grades, chemistry suggests all kinds of exciting things—explosions, color changes, strange bubblings, startling transformations,—strongly tinted with the romance that science fiction gives to chemistry. What a pity so many of them are disillusioned!

Chemistry needs somewhat the same reorganization as was sug-

[12] Marcus, A., *op. cit.*

gested for high school physics. More attention should be given to materials with which the pupils are familiar. True experiments should replace many of the stereotyped laboratory exercises. The problem solving approach should be used extensively throughout the course. Pupils should be encouraged to engage in extensive project work. Most important of all, the preparatory function should be minimized and pupils should be allowed to follow up special interests and develop along lines in which they show special ability.

Minor electives in science. The 1948-50 survey by the United States Office of Education produced a remarkable list of science electives that were offered in our schools: Except for physics, chemistry, and biology, most of the courses had such small enrollments that the report did not even bother to give the enrollment figures. And for all the more common electives the total enrollment was less than that of physics alone.

Low enrollments do not mean that such courses are of small consequence. There is a great need for additional science electives in our schools, and many young people would benefit greatly by taking properly designed science electives.

The problem of providing adequate science electives is made difficult by pressures for teacher time and for laboratory space. Many small schools are just barely able to maintain the three major electives by alternating them with each other or with other subjects. Experimentation with additional electives has been done generally in the larger schools.[13]

There is also a shortage of adequately trained teachers. It is difficult to find sufficient personnel to handle the conventional program, which, because of the demand, must be given preference. In addition, not all science teachers are capable of handling science electives for pupils who wish "non-academic" electives in science. Such courses need teachers with a great deal of understanding of pupil problems. Teachers who think only in terms of rigorous treatment of subject matter fail completely when they try to teach these broader courses.

Pupil programs are crowded, too. After requirements in English, social studies, and physical education are met, there are not many periods remaining for electives in language, fine arts, mathematics, science and the many fascinating technical subjects. Science does not fare well in the competition save among the most academic-minded pupils. Perhaps the nature of the electives has been at fault and perhaps some better designed courses would boost enrollments.

Table 7, page 79, lists some of the many attempts to provide science courses for pupils who might not benefit from the usual courses in

[13] Johnson, Philip G., *The Teaching of Science in Public High Schools*, Bulletin 1950, No. 5, United States Office of Education, Washington, 1950.

physics, chemistry and biology. Of these, the most popular is advanced general science, which by its title implies an extension of the work of the ninth grade at a more mature level. Related science is similar to advanced general science in scope but the emphasis is upon applications of science to situations familiar to pupils. The organization is consequently much different.

Johnson, in a survey of 755 schools, found a number of them offering courses in applied physics, applied chemistry, and applied science.[14] These courses are usually less rigorous than the academic courses they parallel. Physical science is occasionally offered as a substitute for physics and chemistry. It shows promise of making important contributions but is not attracting any great enrollments as yet. Consumer science was once hailed as an excellent terminal science course for pupils who would not go to college, but it has not lived up to expectations.

Courses such as those listed above require very special handling and they require excellent teaching facilities. The boys and girls in such courses are the pupils who lack the special abilities of those who major in science. These pupils have done only moderately well in general science. They do not have much confidence in their ability to succeed in science.

Such pupils need courses that are based upon first-hand experiences. Classes should be small. Emphasis should be upon field and laboratory work. Much of their class time should be devoted to project work and the solution of individual problems.

In practice, conditions for these courses have been almost diametrically opposed to the ideal. Classes have been large. They have been assigned to standard classrooms without the vital facilities for independent work. The assumption has often been that these "second rate" individuals cannot benefit from real science work. Teachers have been at fault, too. They have used texts and classroom discussions rather than the discovery approach. There has been little challenge in many of the courses.

Physical science courses, which attempt to combine the less rigorous portions of physics and chemistry into a unified whole, have been designed to provide laboratory work. If these courses will allow adequate time for learning through first-hand experiences, the slower readers and the less academic-minded pupils will be able to profit. Unfortunately, many of the courses are dominated by the college tradition and so are of little value to the pupils for whom they are designed.

[14] *Ibid.*

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[13] Johnson, Philip G., *The Teaching of Science in Public High Schools*, Bulletin 1950, No. 5, United States Office of Education, Washington, 1950.

their superior abilities. Although special funds are commonly appropriated for the education of the mentally and physically handicapped, little or no provision has been made for the gifted. Benjamin Fine, writing in the *New York Times* of October 10, 1953, states the situation succinctly: "Generally the student on the upper intellectual scale is left pretty much to shift for himself." Some of these boys and girls are able to make progress on their own initiative. The wonder is that so many of them do. The remainder drift into mediocrity.

In recent years the critical shortage of leaders, particularly in the scientific fields, has focussed attention on the problem, and there is increased experimentation in the area of educating the gifted. Fortunately, there have been foresighted educators who have blazed trails that others may now follow.

Some schools have introduced special "honors" classes in the sciences, in which pupils with unusual science aptitudes and interests can find an enriched and accelerated program. Unfortunately, such classes are often arbitrarily dropped by administrators because of difficulties of scheduling. "Honors" programs have also been attempted in schools large enough to maintain a section that parallels the other sections of the regular program. In these programs, pupils pursue an entire program that is enriched and accelerated. Even in many extracurricular activities they tend to be set apart.

New York City has led the way in establishing high schools devoted entirely to pupils with high scientific aptitude and interests. Of the 600,000 gifted pupils in the entire United States, at least 200,000 live in cities large enough to afford such specialized schools.

Although statistics cannot be gathered, the greatest amount of experimentation in this area has been done by individual teachers who have tried to enrich their regular science classes for the benefit of the occasional gifted pupil assigned them. By individualization of instruction, by science clubs, by informal guidance, these teachers have done much to provide this nation's top scientists.

Adaptations of the regular program. A survey of the United States Office of Education based on a sample of 850 schools of over 300 pupils lists thirty techniques, provisions and procedures teachers consider to be "extremely" effective in teaching science to rapid learners. These techniques, provisions and procedures are listed below, in order of their frequency of use:

1. *Insist that the students report science experiments honestly and accurately*
2. *Encourage students to use scientific encyclopedias and references in preparing science reports*

Earth science is not a popular science, as table 7 shows. It does have interesting possibilities, however. It deals with things which pupils see all about them. It is well adapted for firsthand experience learning. It can be taught entirely on the problem solving basis. It is challenging to all types of pupils. Many schools use it as an alternate elective for physics or chemistry and recommend it to pupils who are interested in science but who would not do well in physics or chemistry. Other schools use it to replace ninth-grade general science for pupils of superior ability. New York State is recommending it for this last purpose.[15]

The greatest handicap to earth science as a popular elective is the domination by the college sciences. Language tends to be unnecessarily difficult. Laboratory exercises are patterned on college geology courses with hours spent on the identification of purchased specimens, on the reading of topographic maps, and the coloring of geologic maps. It can, however, be organized to utilize simple language and to deal with familiar problems. It can answer the need of many schools for an additional science elective.

PROVISIONS FOR GIFTED PUPILS

The most casual survey of the entries in the annual Westinghouse Science Talent Search produces convincing evidence that there are in the general school population some boys and girls of remarkable scientific ability. If the survey is extended to include state and regional science fairs, it reveals some of this nation's potential in science.

The Educational Policies Commission of the National Educational Association expresses the conviction that the highly gifted and the moderately gifted pupils make up the top ten percent of the school population.[16] Of the six million boys and girls in public high schools, 600,000 have an IQ above 120 and include most of tomorrow's leaders in business, politics, professions, sciences, and the arts.

A large number of this 600,000 gifted group must have a considerable amount of scientific talent, far more than is evidenced by the Science Talent Search, science fairs, and the entrance into scientific professions. The waste of all this ability is the result of sheer neglect. Exceptional pupils have rarely been adequately challenged to develop

[15] *General Science, An Outline of the Scope and Content of the New Syllabus*, New York State Education Department, Albany, 1956.

[16] Educational Policies Commission of the National Education Association and the American Association of School Administrators, *Education of the Gifted*, National Education Association, Washington, 1950.

It is impossible to judge from the statements alone just what a teacher means by these "techniques, provisions, and procedures," and equally impossible to judge how they are used and how effective they are. Certainly as they are stated a large majority of them do not seem well designed to stimulate talented pupils. And those which have evident possibilities, such as serving as assistants, carrying on independent research, participating in planning, competing in science fairs, forming science clubs, and working with contract units, rate low in frequency of use.

Such statistical evidence as the above does not give a very promising picture. Terman sums the matter up tersely: "Attempts are sometimes made to enrich the program for especially bright children in the ordinary classroom, and such programs at their best can be very helpful. Unfortunately, the so-called enrichment often amounts to little more than a quantitative increase of work on the usual level." [17]

An "honors" program in science. One well-known honors program in science is the remarkable program introduced by Paul Brandwein in the Forest Hills High School. This program is past the experimental stage, having been developed in 1941 and in continuous operation since then.[18]

The Forest Hills Honors program in science begins officially in the tenth year but interested pupils in the ninth grade are encouraged to work in the science laboratories on their free time. This enables them to explore their own interests and allows teachers to become better acquainted with individuals who might become members of the honors program.

Any pupil who intends to pursue a career in science may enter the honors program on his own request. Others who show promise are invited into the program by the science staff members. Undoubtedly there is a good deal of unofficial and informal guidance involved in all decisions to enter the program. No pupil is permanently committed to the program; many transfer out and about an equal number enter to take their places.

Once in the program, the pupils are placed in special sections of biology, physics, and chemistry, designated as "honor" classes. The work in these classes is both enriched and speeded up as compared with standard courses. The pupils are required also to take additional

[17] Terman, L. M., and Oden, M. H., "The Stanford Studies of the Gifted," *The Gifted Child*, Paul Witty, ed., The American Association for Gifted Children, Heath, Boston, 1951.

[18] For a more detailed account of this program together with a discussion of results, read: Brandwein, P. F., *The Gifted Student as Future Scientist*, Harcourt, Brace, New York, 1955.

3. Include activities to stress basic skills such as reading tables, observing experiments and spelling
4. Guide students to note superstitions and other biases that block fair consideration of evidence
5. Give students experiences in helping with science demonstrations
6. Help students understand scientific reasons for fire-safety rules, sanitary standards, and first aid
7. Discuss with students the qualities that help a person hold a job in industry
8. Encourage students to read stories about famous scientists
9. Teach students to read and evaluate science materials from newspapers
10. Guide students to evaluate science notebook work against appropriate standards
11. Stimulate pupils to plan and carry out projects of the experimental research type
12. Encourage students to collect clippings on the uses of science in everyday life
13. Arrange for students to become assistants for class, laboratory and science club work
14. Encourage students to engage in recreational reading of science fiction
15. Help students understand how tools, such as the hammer, plane, drill, and screwdriver, operate
16. Announce and conduct discussion of radio, television, and movie presentation of scientific events
17. Help students analyze information in statistical form
18. Help pupils participate in pupil-teacher planning to discover real problems for study in science
19. Instruct students to repair simple home appliances such as toasters, extension cords, and lamps
20. Guide students to know the values of foreign languages for work in the sciences
21. Encourage students to participate in adult activities, such as providing information about sewage disposal systems
22. Arrange for students to try competitive science examinations and aptitude tests
23. Encourage students to study the science that underlies proficiency in special interests such as music and art
24. Use contracts and other methods that provide for learning activities at different levels
25. Help students to visit establishments where scientific products are made or used
26. Help students participate in local science fairs and congresses
27. Make use of puzzles and magic in teaching science
28. Expect students to make written reports on scientific happenings for the school paper
29. Arrange for doctors, nurses, engineers and others to meet with science classes
30. Arrange for students to attend meetings of science teachers and scientists

Pupils who apply for admission to the Bronx High School of Science are selected on the basis of an examination which may be supplemented by an interview that explores the applicant's interest in a science career. During the first year in the school, equivalent to the ninth grade, pupils study units which are integrations of the usual high school subjects. To supplement regular instruction, trips, movies, and guest speakers are used extensively. Pupils have opportunities to work in the laboratories on projects of their own choosing.

In the tenth grade, the curriculum proper begins. Emphasis is upon general education with opportunities to pursue special interests. Upon graduation, pupils in this curriculum will have studied four years of English, four years of social studies, three years of a language four years of science, three or four years of mathematics, four years of health education, and courses in music and art appreciation.

In his science program, a pupil has the opportunity to follow up his tenth year biology course with an elective course in clinical laboratory techniques, field biology, or nutritional science. The physical science program includes physics, chemistry, industrial arts and mechanical drawing. These courses may be followed by electives in aeronautics, electronics, motor engines, elementary qualitative analysis, elementary organic chemistry, historical development of science, advanced drafting and advanced science laboratory techniques. Each course is liberally provided with opportunities for individual laboratory work and individual projects.

The achievements of the Bronx High School of Science are worthy of more extensive investigation than can be given here. Meister gives the following data for the graduating class of 1947: Of the 285 graduates, 283 were in college the next year. They had received 579 acceptances from 78 different colleges. They were awarded 125 scholarships worth $160,400.[20]

Bronx High School of Science pupils have won more scholarships and honorable mentions in the annual Science Talent Search than the pupils of any other school.[21] One sixteen-year-old was elected a Fellow

[20] Meister, M., *op. cit.*

[21] Although this record is remarkable, even more spectacular is the record of the Forest Hills High School which is not a school for gifted students as are the Bronx High School of Science and the Stuyvesant High School. The records up through 1954 are:

	Finalists	*Honorable mentions*
Bronx High School of Science	18	84
Stuyvesant High School, New York	17	54
Forest Hills High School	17	57
Evanston Township High School	8	
Brooklyn Technical High School	8	
Midwood High School, New York	8	

mathematics and language so that upon graduation they have had four years each of science, mathematics and a single language.

After one term in the program, pupils may enter an advanced science class which permits the pupils to work upon projects of their own choosing. Pupils also have the following opportunities:

1. to engage in original research
2. to publish papers
3. to learn special science laboratory techniques
4. to gain skill with science materials and instruments
5. to gain skill in shop work
6. to engage in library research
7. to take special mathematics courses as far as calculus
8. to take a college physics course
9. to engage in seminars of the Science Society and the Mathematics Honors Society
10. to prepare exhibits for science fairs and to compete in the annual Westinghouse Talent Search

Much emphasis is placed on projects and genuine research. Examples of some of the projects as listed by Brandwein are:

1. Do zygospores of *Rhizopus nigricans* germinate?
2. How long does digestion take in the food vacuoles of different protozoa?
3. Why does *Chaos chaos* seem to have only a regional distribution?
4. What is the effect of ultraviolet on flour beetles fed with buckwheat?

That pupils benefit from their special "honors" classes in science is unquestioned. It seems likely, however, that their greatest benefit derives from the close contact between these young people and a group of stimulating, professionally dedicated teachers. Results are spectacular. In thirteen years 354 students have graduated from the program. Ninety-five percent of these have gone to college and ninety percent are committed to a science career. Several hold Ph.D.'s in science and have made significant contributions to research.

It is impossible to determine whether these 354 students would have succeeded equally well in a standard program. It is doubtful, however, whether any other regular high school of the same size (3,400) can point to similar achievements.

A high school of science. The Bronx High School of Science is one of the several specialized high schools provided by New York City for its boys and girls. It is one of four that tend to attract pupils of high academic ability.[19]

[19] For a competent description of this high school written by its principal read: Meister, M., "A High School of Science for Gifted Students," *The Gifted Child*, Paul Witty, ed., The American Association for Gifted Children, Heath, Boston, 1951.

their pupils equal opportunities. They encourage independent work in the classroom and outside. They employ various types of grouping. They detach individuals or small groups for work on special projects. They sponsor science clubs and other out-of-class science activities. They use the stimulus of science fairs and congresses to develop special talents.

These techniques can be used in some degree in any existing school system. Additional techniques can be devised. Thus the problem can be met in large part by science teachers themselves without special help. For a complete solution, school administrators and the public must be convinced of the need for broader educational opportunities so that they will provide the moderate-sized classes, large classrooms, libraries and workshop facilities, and generous supplies needed to help each young person develop himself to the utmost.

A well informed public. Scientific advances tend to proceed faster than the general public's ability to use them wisely. Bulldozers are ripping out segments of natural beauty before most citizens have become aware of the value of these assets. Each city dump testifies to the disregard for waste of non-renewable resources. Large numbers of adults refuse to be inoculated against epidemic diseases because they do not recognize the explosive nature of such epidemics.

The general public is in an excellent position to learn about each new discovery but many people are unable to grasp the significance of the information presented to them. They do not have a background sufficient for interpreting properly what they read and hear.

Strategically, the secondary school science program is in a good position to give young people the background they will need as adults. The program can give both information and the techniques for gaining information. This does not imply that the science program should attempt to pump more and more information into young people. The goal should be an informational base upon which later learnings can be built together with a strong interest in pursuing a subject further after formal schooling has ended.

A critical public. Undoubtedly the average citizen today uses more discrimination in the conduct of his personal and public affairs than did his counterpart a century before him. Nevertheless, there are still too many people who are swayed unduly by the repetition of slogans, by appeals to the emotions, by pseudo-scientific claims, and by other tricks of persuasion. All too commonly the decisions thus affected result in harm to the individual and to society.

Science education has always had as one of its major objectives the development of critical thinking; that is, reflection upon the conse-

of the Royal Microscopic Society of London. Another discovered a new species of fruit fly. A third discovered a new variety of a mold which has been named H.S.S., the initials of the school. A number of pupils have contributed to leading scientific journals. Of the alumni, about 300 are doctors or dentists, 1500 are engineers, 200 are doing research, 500 are laboratory technicians, and 1000 are teachers of science in high school or college. (These figures are for 1950.)

CHALLENGES TO SCIENCE EDUCATION

Science education has much of which it can be proud. As part of the general curriculum it has helped break down social stratification and increase opportunities for all, a process that has proceeded at a phenomenal rate As a special subject it has helped train men who have been responsible for our amazing technological development, which has brought standards of health and comfort undreamed of a few centuries ago.

There still remains much to be done, and the science program has its share of the obligations both as part of the general curriculum and as a special subject. Much can be done by improving present practices and by speeding up existing procedures. A few problems demand completely new approaches; for these there must be deliberate planning, experimentation, and careful evaluation of results.

Equal educational opportunities for all. Magnificent progress has been made towards providing schooling for all young people. However, equal opportunities for schooling do not guarantee equal educational opportunities. Whenever pupils attend classes in which the work is too easy or too difficult they are being discriminated against because they are being denied opportunities to make the most of themselves.

Any mass instruction technique—a film, a lecture, a demonstration—presumes that all pupils are in the same stage of development, an obviously false premise. All pupils are required to sit through the same presentation—those who already have the required learnings or could gain them in a relatively short time, those who have no interest in the material but would like to study another topic in great detail, and those who are not yet ready for the presentation and cannot benefit from it. Mass instruction is inefficient, wasteful of pupil time and potential.

Completely individualized instruction might seem to be the answer to equal opportunities but there are both practical and philosophical objections to this practice. The solution must fit within the present school framework and it must permit work in the social setting.

Some science teachers have taken important steps towards giving all

Increasing numbers of technologists. There is every reason to be proud of present-day technology. It has given the world standards of health and comfort undreamed of a few centuries ago. This progress has been made possible by scientists who have concentrated upon making scientific discoveries useful. In any plans for altering the emphasis of secondary science, we should not impetuously throw away the practices that have helped make our technology possible.

The production of scientists, many of whom have gone into technological research, has increased at a fairly steady rate, though disturbed by two wars. At the very least present increase rates must be maintained; an improvement in the rate of increase might speed up scientific developments accordingly.

More scientists for basic research. American science is frequently accused of being completely technological. Such harsh criticism probably does not represent a firm conviction about the shortcomings of the United States; certainly no one can rightfully claim that American scientists have made no significant contributions to basic scientific discoveries. However, there is enough truth in the accusation to warrant some self-appraisal. American science has always benefited greatly by a steady transfusion of European-trained scientists. Nearly all the "named" discoveries made in this country bear the names of these European immigrants. Eliminating nationalistic pride from the discussion, we still find reason for questioning the type of education young people receive in this country.

A broad view of the problem is needed. Agonized pleas to return to "the good old days" with a "good, solid course in physics" is not the answer; today's scientists are a product of the good old days. Probably a serious look at European methods is needed to find techniques that can be transplanted. Perhaps present experiments in isolating exceptional pupils will bear fruit. Maybe basic attitudes towards scientific work must be changed in the entire population. In the light of the current trend in international affairs, this problem is one of the most pressing in American education.

Suggested activities

1. Study in detail the science program of a typical school system—the required courses, the electives, the sequence, the prerequisites. Also if possible, determine the enrollment in each course. Calculate the percentage of pupils taking each science course. Compare these figures with the statistics on page 80.
2. Write to a number of institutions of higher learning for their catalogues. Determine the entrance requirements for these institutions

quences to be expected if a proposed course of action is taken. The secondary school science program, which deals with young people still in the formative years but old enough to deal with mature problems, can do far more than it has in attaining this goal.

In working towards habits of critical thinking, science teachers must reconsider the content of most science courses. These last have become so crowded by the addition of more and more information that little time is left for reflective thinking. Content must be presented so as to permit the consideration of the significance of the material, and the material itself must be selected with a thought as to its usefulness in attaining the above objective.

An adequate supply of technicians. Automation is producing startling changes in our methods of production. Men with shovels, wrenches and hammers are disappearing. Taking their places are the men who install, operate and service machines which are taking over the work of unskilled laborers.

Technicians are in their way scientific personnel just as are engineers and chemists. Their training is usually short and often taken on the job. But they deal with things of science and they must think in terms of science. They represent a vital segment of today's society.

The secondary school is at the ideal level for the recruitment of technicians, most of whom begin work immediately after graduation from high school or after a short, intensive training program. The secondary school is not called upon to train technicians, but it should take upon itself the developing of strong scientific interests, the identification of those with suitable characteristics, and the guidance of these young people into appropriate lines of work.

The typical secondary school science program of the past has done little for the recruitment of technicians; it may even have interfered with the process. Emphasis has been upon college entrance. Pupils lacking high academic ability have been firmly excluded from senior high school elective courses. Many youngsters have been convinced that they have no aptitude for science and have developed in consequence a strong distaste for any type of work in scientific fields.

Two alternative procedures suggest themselves as answers to the problem. Present courses may be broadened to provide for a greater range of interests and abilities. This must be done with extreme care, however, lest the academically superior pupils suffer. Or more courses may be introduced for pupils of lower academic ability. This plan calls for early identification of talents and deliberate recruitment of pupils for the new courses.

Part II

The special techniques of science teaching

Science teaching utilizes a number of techniques, each of which makes its special contributions to the learning process. The science teacher uses these techniques to insure the maximum growth of his pupils, in terms of both factual learnings and improved ways of thinking and behaving.

Using this information, plan a high school program that you would recommend for a pupil who desires to enter one of the scientific professions

3. Obtain science courses of study from a curriculum library or by writing directly to state education departments. Compare the programs suggested.

4. Select a school system using the 6-6 plan, the 8-4 plan and the 6-3-3 plan (or other variations). Compare the science programs offered by these systems. How well does each of these programs coincide with the proposed 12-year program suggested in the Thirty-first Yearbook of the National Society for the Study of Education?

Suggested readings

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PUPILS SHOULD EXPERIMENT

chapter 5

Experimentation is so much a part of science that it is difficult to conceive of a science program without this type of activity. One of the major objectives of the science program has always been the development of an understanding of the experimental method; this was true even during the early days of formal science training in secondary schools. There has always been provision for some type of laboratory work and for experimentation in secondary school science.

Experiments and laboratory work are almost—but not quite—synonymous terms in the secondary school science program. There may be some experimentation done outside the laboratory, and some laboratory activities cannot be called experiments. But in practice most of the experiments done by pupils are part of their laboratory work and most of their laboratory work involves experimentation.

Laboratory work, at its best, is an integral part of the science program, developing naturally out of other types of activities, and in its turn leading towards other forms of class work.

Mr. Johnson began a biology lesson with the question, "Does your heart beat faster when you are standing or when you are sitting?" The pupils speculated that standing might represent a form of exercise but resolved that they could answer the question best by experimenting. They chose to test themselves individually, letting Mr. Johnson serve as time keeper while they determined their respective heart rates. Results were entered in a chart on the blackboard.

Analysis of his procedures shows: (1) a statement of the problem; (2) a single trial with an accompanying observation; and, (3) a conclusion. The pupil considered a single trial to be sufficient because he could not conceive of conditions that might affect his results differently. His conclusion was simple and direct. Though experts in science education may be critical of his procedures, their objections tend to cloud what is otherwise a satisfactory solution. Many problems can be solved by this three-step attack.

Complexities arise in situations in which several factors are operating. Then conclusions that result from a single observation need reconsideration and retesting under varying conditions to determine their validity.

Pupils who were studying the bleaching effect of sunlight recalled that newspapers left outdoors turned yellow rather than white. Two pupils volunteered to set up some experiments to see whether yellowing is the result of exposure to sunlight.

A few days later the pupils displayed strips of newsprint that had been left in a sunny window. From the appearance the class concluded that sunlight was responsible. Their teacher, however, hinted that other factors might have caused the yellowing. The pupils listed some of these factors and devised experiments to test their effects. After these experiments had been tried out a final conclusion with needed qualifications was proposed and accepted by the class.

Sometimes the need for retesting as illustrated above can be anticipated and made a part of the original experiment. This results in what is known as a "controlled experiment"—a device that will be discussed in the section that follows.

When attacking complex and difficult problems, researchers usually add another step. They investigate the findings of others who are working in the same or related fields. These investigations may suggest methods for the attack upon new problems. Sometimes they reduce the amount of information that must be gathered. Occasionally they reveal that the problem has already been solved in whole or in part. This step is not one of general use in the secondary school science program because of the lack of library facilities. It may be used by occasional pupils who can visit nearby colleges and large public libraries.

Controlled experiments. Many science teachers prefer to restrict the term "experiment" to the type of investigation known as the "controlled experiment." In the controlled experiment, every effort is made to control the factors involved. All factors but two are held as nearly

Several new questions arose as the data from the experiment was being considered—sex differences, variation in rate as exercise was increased, individual variation for the same amount and kind of exercise. They chose to answer these questions by working in pairs and pooling data afterwards.

Mr. Johnson brought the lesson to a close with a general reading assignment and a brief consideration of other factors that affect heart rate—fear, anger, age, drugs, and the like. Almost immediately pupils began volunteering to conduct studies of these factors outside of school hours.

In this lesson it is difficult to draw a sharp line between laboratory work and other forms of class work. The original problem led to a general class experiment. The results gave rise to more problems best solved by small groups; procedures used were useful in suggesting a pattern for attack. The results of the small group experiments led to a general reading assignment and to continued experimentation as a permissive assignment.

THE NATURE OF EXPERIMENTS

In a broad sense many activities can be listed as experiments. A pupil mixing orange juice and milk "just to see what happens" is experimenting. His purpose is vague, his procedures are not clearly thought out, he has no controls and no plans for making observations. He may draw no conclusions. But he is trying something without knowing the outcome.

Experiments range from these simple activities to exceedingly complex attacks on problems. From the teaching standpoint, the simpler experiments are important because the attacks used are more readily adapted to the everyday situations pupils encounter. Highly formal experiments have little application in the lives of young people.

There is always danger that teachers will think only in terms of complex experiments, over-formalizing the experimental method until it becomes valueless to adolescents. At its best, the experimental method is flexible and readily adapted to all types of situations. Generally, it is no more than the application of common sense to the solution of problems.

The "steps" of the experimental method. The great majority of problems solved by experiments are so simple that no one bothers to isolate the successive steps used in the attack. There are steps, however, and these may be discovered by analyzing the procedures used.

A pupil raised a question, "Will ice float in kerosene?" He procured a bowl, some kerosene, and a piece of ice. He dropped the ice in the kerosene, noted what happened and made a statement.

Analysis of his procedures shows: (1) a statement of the problem; (2) a single trial with an accompanying observation; and, (3) a conclusion. The pupil considered a single trial to be sufficient because he could not conceive of conditions that might affect his results differently. His conclusion was simple and direct. Though experts in science education may be critical of his procedures, their objections tend to cloud what is otherwise a satisfactory solution. *Many problems can be solved* by this three-step attack.

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constant as possible. Of the remaining two, one is varied and its effect on the other is determined.

Two high school physics pupils were working with a direct current motor. They applied a uniform voltage to the rotor. They varied the voltage impressed on the field coils by uniform steps and determined the speed of the motor for each step. They plotted their data on a graph.

Sometimes two parallel experiments are set up so that comparisons can be made One of the two experiments is often called a "control" or a "check."

Two seed flats containing soil from a lawn were planted with a standard lawn grass mixture One flat was watered with rain water, the other with rain water containing a little ammonium sulfate. The flats were kept in the same place to insure identical conditions of temperature and light.

In the above experiment, the seed flat watered with rain water alone is termed the "control." It would have been possible to conduct a large number of parallel experiments using flats watered by solutions of different concentrations of ammonium sulfate. The flat watered with rain water would still have been termed the control.

Sometimes it is difficult to identify a "control" in a set of parallel experiments.

A pupil was attempting to discover the effect of temperature on the rate with which sodium chloride dissolves. First he put a measured quantity of salt in water at 20° C. and stirred the liquid until the crystals disappeared, noting the time required. He repeated this experiment using water of different temperatures. He graphed his findings as a curve of time against temperature.

In the above experiment, if the pupil used identical containers for each phase of the experiment, if he measured out equal quantities of water and salt each time, and if he standardized his pattern for stirring the liquid, he controlled all factors of his experiment. There is, however, no "control" as illustrated in the previous experiment.

It is usually difficult to control the factors involved in experiments with living things because of the variation of individuals.

A general science teacher proposed an experiment with white rats to show the nutritional value of milk. Two rats were procured and kept in similar cages. One was given a diet of bread and milk; the other was given a diet of bread and water. Plans were made to keep records of the increase in weight of the two rats. However, the rat on the milk diet actually lost weight and died at the end of the fourth week.

Individual variations may be averaged out by using large numbers of individuals. Generally, the samples tested should be as large as possible, involving dozens if not hundreds of individuals.

Sometimes it is not practical to experiment with large samples. Smaller groups may be used if careful attempts are made to equate the groups in size, weight, general health and other observable characteristics.

For an experiment to see if the movement of the sun causes the twining growth of certain climbing beans, fifty beans were planted in identical containers and given constant conditions until the seedlings were about three inches high. Then three groups of ten each were selected, the individual plants being as nearly alike as could be judged by their appearance. One group was put in a window where they received direct sunlight all day. A second group was kept in a north window where no sunlight was received. A third group was kept in darkness.

When it is necessary to work with a few individuals only, it is possible to expose the individuals to first one set of conditions and then another, comparing changes noted under the two conditions.

A young chicken was fed a standard balanced diet for three weeks, then a diet deficient in Vitamin B for three weeks, and then the balanced diet for three weeks. Weight was determined daily and conclusions were drawn from the comparison of weight changes.

Laboratory exercises. Many activities carried out in science laboratories and labeled "experiments" are little more than exercises with laboratory equipment. Some are frankly designed with a single purpose—to familiarize pupils with certain pieces of apparatus or with certain skills. Many are designed to demonstrate certain principles.

The chief distinction between an "experiment" and an "exercise" lies in the information given to the pupils. In an experiment, a pupil does not know what the results of his investigations will be. In an exercise he is told precisely what the outcomes of his work should be and how to attain them.

Mr. Mulvaney directed his physics class to balance unequal weights on meter sticks and then calculate the moments in each case. He emphasized that in each case, clockwise moments must equal counter-clockwise moments, and that pupils should repeat measurements until equality was attained.

Pupils vary greatly in their reactions to situations in which they are told what to do, what to see, and what conclusions to draw. Some work patiently and conscientiously and are pleased when their results come

out as expected. They seem to enjoy the feeling of security that this type of work gives them.

Other pupils demand more challenge. They want to find out things for themselves. They are stifled by cut-and-dried exercises. The ideal program provides opportunities for both types of personalities.

Standardized laboratory exercises probably owe their misuse to the relative ease with which they are conducted. A teacher need only provide his class with materials and a set of directions. After a little experience he is able to anticipate almost all the difficulties and need give little attention to his class during the laboratory period. His program conforms with the traditional concept of laboratory work and he feels no compulsion to provide more challenging problems for some of his pupils. A conscientious teacher, however, recognizes the strengths and limitations of standardized laboratory exercises. He makes use of them to enrich his program and he provides other types of activities for pupils who need them.

The introduction of new techniques and new apparatus provides an element of discovery that appeals to pupils. Early experiences with microscopes are stimulating to pupils in a biology course. An introductory exercise with glass bending helps create a favorable attitude towards general science.

Standardized laboratory exercises can be used to initiate independent work for those who have the inclination to do so.

Mr. Weissman provided his physics class with duplicated sheets that gave direction for determining the coefficient of friction between a block of wood and a board. As the pupils worked on the exercise, Mr. Weissman moved from group to group, chatting informally about results and occasionally asking such questions as "Would the force needed to move the block be different if the block were on edge rather than on its face?" and "What is the friction between a gym shoe and the gym floor?" and "How much force could Tom exert in a tug-of-war if he were wearing leather soled shoes on a polished maple floor?" Soon most of the groups were working on such problems. Two groups, however, continued to work with standard laboratory materials, checking their results against data given in a physics handbook.

Contributions of laboratory work. Real scientific experiments, originated and carried out by the pupils themselves, involve high level thinking. The students gain practice in recognizing and defining problems. Their ingenuity is challenged and exercised in devising methods of attack. They become familiar with the limitations of data and the need for caution in drawing conclusions, and they develop the habit of critical thinking.

Some pupils are not ready to undertake original experimentation but they are interested in following up suggestions given by their teacher or the books available to them. If they are allowed to work independently, without continued interference from the teacher, they will benefit as mentioned above, though to a lesser degree. And as they mature and gain experience, they too may undertake original research.

There are some pupils who seem to lack ability for original work. These may benefit from standardized laboratory exercises by learning to follow directions, to keep good records, and to take responsibility for careful work. They will learn much about their strengths and limitations. They may find that the work of laboratory technicians appeals to them.

An important contribution of laboratory work is the broadened appeal this type of work gives to the science program. Adolescents enjoy activities in which they can work together. They like the excitement of the unknown, the opportunities to manipulate materials, the comparative freedom of action, and the satisfaction of tangible achievements. An exciting laboratory program can do much to draw young people into science courses and ultimately into scientific vocations.

PROVIDING UNIFORM LABORATORY EXPERIENCES

Teachers must expect to plan most of the laboratory work done in secondary school science. Occasionally pupils have original suggestions but for the most part are dependent upon the teacher for their ideas. Until pupils have had experience in working alone and following up their own ideas, uniform laboratory activities must be provided.

Uniform laboratory activities have certain advantages. All pupils gain a common background of experiences. Directions and guidance are easier to give when starting a new topic. And out of the uniform work may develop special interests that the pupils may pursue individually.

Selecting laboratory activities. Excellent suggestions for laboratory activities can be found in textbooks and laboratory manuals. Popularized science books also contain excellent suggestions that may be adapted readily for the school laboratory; some of these suggestions are especially valuable because they call only for simple materials and straight-forward procedures.

All suggestions for laboratory activities need careful analysis before they can be included in the program. Some points that should be considered are as follows:

1. Is the purpose easily understood?
2. Can clear-cut directions be given?
3. Are the procedures simple and direct?
4. Can results be obtained in a short time?
5. Are the materials familiar to pupils?
6. Are the materials inexpensive, readily procured and easily stored?
7. Are applications of the findings obvious?

The following are some types of activities that are generally successful in secondary science laboratory work.

Type	*Examples*
Operation of devices	electric bells, telegraph sets
Testing chemical properties	starch tests, acid-base tests
Finding physical properties	focal lengths, hardness of minerals
Microscopic examination	hay infusions, feather structure
Gross anatomy	flower structure, crystal shapes
Internal anatomy	sections of stems, vacuum tubes
Analysis	soil composition, hard water
Simple experiments	heart rates, solutions
Identification	keying leaves, identifying rocks
Preparations	carbon dioxide, conductivity tester

It is essential that the purpose of an activity be readily understood, and even more important that the purpose be such as to challenge pupils.

Mr. Hewitt provided each pair of pupils with a sauce dish to be filled with water, a needle, and a razor blade. He directed the pupils to float the needle and the razor blade on the surface of the water.

Obviously, Mr. Hewitt had surface tension in mind when he planned this activity, but he did not force this purpose on his pupils. Instead he presented them with a problem that genuinely challenged them. Out of the inevitable "why's" would come the development of the desired concepts.

It is common to find teachers forgetting the nature of their pupils and planning activities that have little significance to them.

For an introductory experience with lenses, Mr. Phillips directed the pupils in his physics class to determine the focal length of a set of convex lenses, using the relationship:

$$\frac{1}{D_o}+\frac{1}{D_i}=\frac{1}{f}$$

The pupils followed the directions he gave them but showed little strong interest in the processes. They were careless in their work. They wasted a good deal of time talking and "fooling around."

Mr. Phillips' pupils did not have the background to be interested in this problem and they found little excitement in the procedures used. They would have been far more interested in studying the relative sizes of the images produced. Then, when they recognized the effects of lens curvature, they would be ready to study focal length.

The selection of laboratory activities should be influenced by the need for concise, clear-cut directions. Many an activity, otherwise suitable, fails because the directions are too complex for pupils to follow. Such activities are better suited for special assignments for talented pupils.

Another factor important in selecting activities is the length of time needed to attain results. Pupil attention is apt to drift markedly after fifteen or twenty minutes of one type of activity. Experiments in which results can be attained in less time are best suited for uniform laboratory assignments.

Teachers should consider also the problem of "dead" intervals. Serious problems of discipline may arise while pupils are waiting for water to boil or for filtration to be completed. When such activities are necessary, supplementary activities should be assigned to fill the time.

A deciding factor in the selection of a particular activity may be the type of materials required. Some activities utilize materials that are too expensive to provide in quantity, or too delicate to withstand rough usage. There is also the problem of storage which may prevent the use of bulky or awkwardly shaped items.

In general, it is best to make free use of commonplace and familiar items. Pupils feel at ease with such materials and they see more clearly the applications of their work to everyday situations. They see possibilities for doing equivalent experiments at home.

Complex and specialized equipment has its place in the program but not for introductory experiences. The best use of such materials is in follow-up work when the need for more precise measurements and better controls have become evident.

The pupils in Mr. Stanhope's physics class began a determination of the latent heat of fusion using glass jars for containers. Consideration of the possible errors in the preliminary measurements, however, showed the need for better control of heat transfer. Mr. Stanhope then displayed and explained the action of a calorimeter. The pupils repeated their measurements, this time using calorimeters. Two pupils, however, thought that a thermos bottle would be even more effective and were given permission to use one instead.

The need for obvious applications of laboratory work is not always considered by teachers because of their concern with the learning of scientific principles. Pupils are often set at tasks that to them seem to have little relation to reality. This is one common cause for dissatisfaction with traditional laboratory work.

Laboratory activities utilizing commonplace devices usually show immediate applications. When siphons, candles, electric bells, xylophones and garden soil are studied, pupils rarely question the value of the work.

Over the years Mr. Jordan had acquired a number of damaged thermos bottles that still held water. He supplemented these with several bottles that were intact. Each year his physics class experimented with the bottles to determine the importance of the vacuum in reducing heat transfer. They plotted both the temperature drop against time and the caloric loss against time.

Giving directions for laboratory experiences. The directions for uniform laboratory activities must be explicit; often they outline in cookbook form exactly what to do. There are times, however, when the problem is so simple that procedures can be discovered by trial-and-error. Then no directions need follow the statement of the problem.

Mr. Adams set before his seventh grade science class a carton of dry cells, a number of miniature lamps and sockets, some wire, screw drivers and pliers. He asked the pupils to work in pairs trying to light a lamp from a cell.

Mr. Adams put additional lamps and sockets in his pockets and moved about to check progress. As soon as a team had lighted a lamp he gave it a second lamp with the suggestion that the pupils try to light two lamps from the same dry cell. If the second task was accomplished he gave out a buzzer or a bell in exchange for the lamps. He stopped the activity before all pupils had finished but he provided time later for interested pupils to work by themselves.

Oral directions may be adequate for one-step activities if the directions are simple enough to be remembered.

Miss Stassen told her earth science class that dilute hydrochloric acid reacts with substances containing carbonates. She gave each pair of pupils a dropping bottle of acid and a tray of assorted rocks, minerals, bones and shells. She directed the pupils to test the several items for the presence of carbonates.

Sometimes it is wise to summarize on the blackboard directions that have been given orally.

Mr. Bruhn set out test tubes, medicine droppers, a soap solution and a liquid detergent. He showed the pupils how to test the effect of these on hard water. He then summarized the directions on the blackboard as follows:

1. Fill two test tubes nearly full of tap water.
2. Add four drops of soap solution to one test tube.
3. Add four drops of detergent to the other test tube.
4. Shake each test tube well.
5. Hold the test tubes up to the light and observe.

When pupils participate in planning an experiment it is also a good idea to summarize on the chalkboard the directions finally agreed upon.

Mr. Bertone's physics class was studying the pendulum. Mr. Bertone had suspended an iron ball from a long thread. He set the ball swinging and raised questions about the factors that might affect the period of swing.

Pupils suggested such factors as the length of the thread, the weight of the ball, and the amplitude of the swing. They planned several short experiments to test the effects of these factors. As each experiment was planned, Mr. Bertone wrote down the steps to be followed.

Previously prepared direction sheets can be great time savers but these must not be used mechanically if the desired goals of the science program are to be attained. Such sheets are rarely stimulating in themselves. They need the same careful introduction as has been described for oral directions. Perhaps the best use of prepared sheets is for giving "recipes" for doing things that appeal to pupils.

Miss Gilmore introduced her ninth grade science class to the study of photography with an exercise on the development of photographic paper. Four sets of trays containing developer, fixer and stop bath were placed on the laboratory tables. Eight printing frames and several envelopes of printing paper were also provided. Then Miss Gilmore passed out sheets containing the following directions:

TO MAKE A PHOTOGRAPHIC PRINT

Work only in a darkened room or in a dark room lighted by a photographic safelight.

Materials Needed:

A tray of developer	A printing frame
A tray of stop bath	Printing paper
A tray of fixer	Ferrotype plate or blotters

Procedures:

1. Put a sheet of printing paper, glossy side up, in the printing frame.
2. Put something opaque, a rubber band, a leaf or a cut-out on the printing paper and close the frame.

3. Expose the paper to strong daylight for one minute.
4. Put the paper in the developer for 45 seconds.
5. Wash the paper in the stop bath for 20 seconds.
6. Put the print in the fixer for 10 minutes.
7. Wash the print in running water for 30 minutes.
8. Dry the print on the ferrotype plate or between blotters.

Miss Gilmore read through the sheet with the pupils showing them the materials to be used and indicating certain cautions about some of the problems that would be encountered. Volunteers were selected to return later to take the prints from the wash water and put them on the ferrotype plates. The shades were then drawn and the pupils began work.

If the directions for an activity are at all complex, and particularly if many cautions are necessary, it is usually well for the teacher to perform portions of the experiment on a demonstration basis before setting the class to work.

Mr. Stillwell assigned his class the task of preparing oxygen from potassium chlorate following the directions given in the laboratory manuals. He displayed the materials needed and showed the pupils how to assemble them. He followed the printed directions and gave the reasons for using the required angle for the combustion tube, for the specified way of heating the tube (he demonstrated with an unlighted burner) and for the method of ending the heating process in order that water be kept out of the combustion tube.

Then Mr. Stillwell asked different pupils to repeat the reasons for each of the special procedures. Only after this did he permit the pupils to begin work. Over the years he has had little breakage and no serious accidents during this particular exercise.

Providing materials for laboratory work. A rich program of laboratory experiences calls for materials in sufficient quantities so that each pupil is able to participate. Usually duplicate sets of materials are needed. In some teaching situations the problem of obtaining and storing adequate materials is difficult to solve but is never so critical that laboratory work has to be eliminated altogether.

In a well-balanced program, laboratory experiences will be provided only two or three times a week at most, other class periods being built around field experiences and project work. Of these two or three periods a week, some will certainly be organized to permit pupils to work on different problems. Sets of duplicate materials, therefore, are needed somewhat more than once a week. There are countless activities that require only the simplest of materials, and, when special equipment is needed, there are various rotational plans that make it possible to get along without duplicate sets.

Countless experiments require only simple and easily procured materials, thus making possible a rich program of laboratory work for all pupils. Here two pupils are testing green leaves for starch. The materials they are using can be provided in duplicate sets so that all pupils can carry out the same experiments simultaneously.

A number of books suggest experiments that can be carried out with materials commonplace in the home or inexpensively purchased in variety stores.[1] These experiments, though using simple materials, involve the same high level thinking as their equivalents carried out with conventional laboratory equipment.

A surprisingly large number of items can be contributed by the pupils. Other useful pieces of equipment can be obtained from articles that have been junked, such as radios and automobiles. Tin cans of all sizes and glass jars have unlimited uses. Pupils can make much of their own equipment, some of which may be added to the general supplies for future use, thus building up laboratory stocks.

The pupils in Mr. Timball's ninth grade science class were studying radiation from different surfaces. To compare radiation from surfaces of different colors, the pupils painted fifteen number 1½ (one pint) food cans with quick drying black paint and an equal number of identical cans with quick drying white paint. During the next period the pupils, working in pairs, filled the

[1] To appreciate the wealth of suggestions for laboratory experiences with commonplace materials, be sure to investigate the following three books: *Science Experiences with Home Equipment, Science Experiences with Inexpensive Equipment, Science Experiences with Ten Cent Store Equipment,* all by Carleton J. Lynde, Van Nostrand, Princeton, N. J., 1950.

cans with hot water, covered each with a cardboard square, and noted the decrease in temperatures.

When the experiment was over, Mr. Timball put the cans in a shipping carton designed for number 1½ cans. He labeled the carton suitably and put it away for later use.

Storage need not be a serious problem if the laboratory experiences are selected with this point in mind. In many instances the materials, when disassembled, occupy little space.

Mr. Timball planned an exercise on copper plating as one of his ninth grade science laboratory activities. The dry cells needed for the experiment were part of his regular teaching supplies and had been used for many other purposes. These were stored in their shipping cartons. Half-pint glass jars, also used for many other purposes, were stored in a suitable shipping carton. Wire and battery clips were part of his regular electrical supplies. All that remained were metal strips which he kept in a cigar box labeled "Copper Plating Experiment."

It is always advantageous to keep special items in labeled cartons or boxes as just described. A great deal of time and energy is saved when the teacher can produce a container earmarked for a certain experiment and know that all the things he needs are in that container.

Sometimes a teacher believes that pupils should have experiences with certain materials that cannot be provided in quantities. In such cases there are various rotational plans that may be employed. In one system, several different experiments are set up about the room. Groups of pupils move from one experiment to another, working at each in turn.

Miss Hotaling set up equipment in her classroom so that when the pupils entered, they found fifteen different experiments set up on the laboratory tables. These experimental set-ups, designed to provide varied laboratory experiences with minimum equipment, were as follows:

1. A ball-and-ring apparatus
2. A taut horizontal wire to show lengthening when heated by an electric current
3. An electric toaster to show lengthening of the element wires when heated
4. A bimetallic thermostat
5. A bimetallic bar
6. An air thermometer
7. A balloon on a flask to show expansion of air
8. Gallon cans balanced on a scale to show relative weights of warm and cool air
9. A convection box
10. A convection operated lamp shade
11. A wafer-type brooder thermostat
12. A flask with one-hole stopper and glass tube to show expansion of heated water
13. A pulse glass

14. An automobile radiator thermostat
15. Soaked sawdust in a large beaker of water to show convection caused by unequal heating

After a few preliminary instructions the pupils divided themselves in groups of two each and drew numbers from a box to indicate the experiment with which each team was to begin. As pupils finished their experiments they moved to the one bearing the next consecutive number.

Beside each set of apparatus Miss Hotaling had previously placed a typewritten sheet bearing directions for the activity to be carried out. She included any needed cautions to reduce breakage or injury.

The pupils were able to carry out a little more than half of the experiments the first day. They completed them the second day.

Miss Hotaling encountered a few problems. Pupils were able to complete some of the activities with comparative rapidity and by moving on prematurely caused some confusion. Also one experiment gave pupils trouble and Miss Hotaling found it necessary to spend most of her time with it.

Ideally, in the type of organization Miss Hotaling used, the experiments should require the same amount of time for completion. Actually this is impossible because pupils work at different rates, but if the activities selected are relatively short, there is less variation in time needed for completion than when lengthy exercises are provided.

Despite the problems Miss Hotaling encountered, her efforts were justified. She was able to provide firsthand experiences with materials that are not effective in demonstrations and that could not be provided in duplicate.

There are several ways that Miss Hotaling could have varied procedures to avoid some of her problems. She could have divided the class in groups of three's, thus reducing the number of separate experiments to ten. By doing so, she could have equated the experiments a little better. On the other hand, opportunities for individual manipulation would have been reduced.

Perhaps Miss Hotaling could have set up seven or eight exercises in duplicate. Then two halves of the class could work in parallel. Or Miss Hotaling might have set up five experiments to be supplemented by seat work. The groups of pupils would then take turns working on the experiments, returning to their seats when they were finished. She would have encountered some administrative problems but these would not be serious.

Sometimes it is possible to permit individual pupils to work at their own speeds. Variation in rate of work quickly separates the pupils so that after the first few exercises, it is unusual for two pupils to be ready for the same exercise at the same time. Use of this technique is most

successful in specialized subjects that permit the teacher to set up a long sequence of individual problems.

Mr. Smith teaches a very successful course in electricity for ninth grade boys. The walls of his laboratory are lined with deep shelves that hold large numbers of "breadboards" standing on edge. On each breadboard are directions for an exercise together with the items of apparatus needed. The exercises range from simple doorbell circuits to the study of rotating electromagnetic fields.

Mr Smith's pupils start with some of the simpler exercises for which he has duplicate breadboards As a pupil completes the exercise he returns the breadboard and takes another with a more advanced problem. After the first two or three exercises, the pupils are usually in different portions of the sequence and duplicate materials are not needed.

The size of laboratory groups. The major contributions of laboratory work result from the opportunities for manipulation that are provided each pupil Opportunities for manipulation are at a maximum when pupils work alone. However, most adolescents prefer to work in groups and there are advantages in allowing them to do so.

Pupils working in pairs usually share manipulation experiences, although one pupil may dominate the other to some extent. But when pupils work in three's or larger groups, many pupils find it impossible to work with the actual materials. One pupil in each group is generally aggressive and dominates all activities. He may allow one pupil to help him but the remaining pupils are left with little to do except observe passively, take notes, or wander off to see what others are doing. Careful planning is needed to provide worthwhile activities for each pupil in larger groups.

The teacher's role during laboratory work. One of the chief objectives of laboratory work is to allow pupils to learn for themselves, by solving the problems that they encounter in their work. After purposes have been defined and procedures outlined, the place for the teacher in the laboratory is in the background. A teacher may move from group to group, giving encouragement, clarifying procedures, straightening out misunderstandings, and stimulating fast-working pupils to undertake new problems. But his presence in the classroom should not be required for successful operations.

A teacher should try to avoid interrupting the work of his class with announcements. Separate groups are in different stages of their work and thinking; if announcements are made, the progress of their activities will be broken, so that time and continuity are lost.

Record keeping. Records are important in so many ways that pupils should know how to keep them well. Science laboratory work may be used to acquaint pupils with several different ways of keeping records.

The form that records take may vary with the needs that they are to fill. No research scientist would handicap himself by adopting one stereotyped format for his records. He might choose one form for one situation and another form for another situation. Nonetheless, many science teachers have done irreparable harm to the cause of science *education by insisting that pupils adopt the following single, highly* stereotyped form:

1. object
2. apparatus
3. procedures
4. observations
5. conclusions
6. applications

Such a form may result in boredom for a large number of pupils. However, it should be recognized that certain pupils like to follow set patterns in their work, possibly feeling more secure than when they have to make decisions about forms to be used.

Simple experiments need only simple records. Indeed, in some cases, *written records are superfluous. There would be little point in re*quiring pupils to make notes on an experiment to find out whether pumice can float on water.

Labeled diagrams are often sufficient for recording experiments. Arrows drawn on a diagram of a beaker of water being heated along one side show the convection currents set up by the unequal heating. Labels indicate the apparatus used. Procedures are self evident. No broad conclusion is possible from this limited experiment.

Graphs and tables often serve as satisfactory records either with or without additional notes. An experiment that shows variation of heart rate after exercise and rest needs only a table of the data collected. The headings on the chart indicate the purpose, the materials used and the procedures. The reader draws his own conclusions from the data.

Except when special materials are used, diagrams or pictures are more effective than words in describing apparatus. Itemization of the component parts of an assembly is rarely needed. Commonplace items such as funnels and gas burners are generally assumed to be used in familiar processes such as filtration and heating.

Procedures need elaboration when they cannot be inferred from diagrams, charts, and graphs. An experiment to discover the effect of air circulation on transpiration rate may require an explanation of how the twig is prepared to maintain an unbroken column of water in the xylem tubes.

Duplicated sheets for use when collecting a large amount of data can be great time savers. Sometimes these sheets may contain directions for gathering the data as well. Such record sheets insure uniform organization of data and are helpful in carrying out discussion of the results. However, these sheets encourage mechanical procedures and may discourage individual initiative. Before prepared sheets are adopted for any particular experiment, the advantages and disadvantages should be carefully weighed.

A form of record keeping that is little used but that seems to have value is an exhibit of materials actually used. Dried and pressed leaves showing the effects of starch tests in phototropism experiments may be mounted on charts as a class project or in notebooks for individual records. Nails that show the factors affecting rust formation may be exhibited with appropriate labels.

Use of data collected. Data are collected in order that questions may be answered. Generally, summaries must be made and certain conclusions drawn. Summaries may be made orally, by filling in the data on charts or by setting up exhibits. Summarization is the usual prelude to drawing conclusions.

Conclusions that may be drawn from laboratory experiences are necessarily narrow. They should be limited to the conditions under which the experiments were carried out. There is a tendency to allow broader conclusions than are justified, particularly in the physical sciences.

The pupils in Mr. Dunlap's physics class were directed to compare the forces needed to draw a metal roller and a wooden block respectively across a wooden table top. The pupils collected the data and concluded that rolling friction is less than sliding friction. Mr. Dunlap accepted this conclusion.

Actually, the only valid conclusion that Mr. Dunlap's pupils could draw was that it takes less force to draw a metal roller across a wooden table top than to draw a wooden block across the same table top. The experiment did not deal with other types of rollers, blocks or surfaces, nor did it deal with large scale materials. The pupils could infer that their findings might apply to other situations but they should not have been permitted to assume that the application is automatic. Actually, there are important situations in which plastic surfaces such as wet clay are involved, when sliding friction is less than rolling friction.

Pupils should be encouraged to gather considerable data before drawing conclusions. Rarely can valid conclusions be drawn from single instances. When time is a factor, pupils may pool their data,

thus providing themselves with a broader base on which to draw conclusions.

Each group in Mrs. Camp's physics class made three trials in determining the latent heat of vaporization of water. As they made each determination they entered the results on a chart on the blackboard. Later they copied this chart in their notebooks. At the close of the exercise, the pupils averaged the figures and drew a conclusion from the result. Since there were twelve groups in the class, and each group made three trials, the final conclusion was based upon thirty-six separate determinations.

INDIVIDUALIZING LABORATORY WORK

Independent laboratory activities confer on pupils certain benefits that are not permitted by uniform laboratory assignments. Pupils become best acquainted with their own interests and abilities when they are working on problems of their own choosing. Their special needs and special talents are best provided for through individualized assignments.

Teachers must know their pupils well before attempting to set up completely individualized laboratory situations. Much must be known about a pupil's likes and dislikes, and his abilities and limitations, before setting him at work with a minimum of supervision. A teacher cannot hope to control the unrelated efforts of a roomful of strangers.

Individualization may begin in a limited way, however, almost from the beginning of the school year. As soon as a pupil displays a special talent or a strong interest, he may be encouraged to begin work on a special problem while others continue with their regular assignments.

Individualization of laboratory work demands of the teacher a certain flexibility of thinking. He must abandon the concept of uniform outcomes and remake his objectives to permit one pupil to learn one set of facts while a second pupil is learning a second set of facts.

Initiating independent work. Pupils do not often suggest completely original problems that they would like to undertake in the laboratory. Their teacher usually finds it necessary to provide them with specific suggestions. However, once pupils learn that they are free to adapt these suggestions or to originate their own, they become much more independent.

Some pupils display more originality in proposing problems than do others. Undoubtedly the nature of the experience background is important. Practice also seems to be a factor. Pupils who are used to taking the initiative are more productive of ideas than pupils who have always been compelled to follow directions.

One technique for encouraging pupils to work independently is to give them a list of problems from which they may make choices. It is wise to suggest more problems than will be selected so that some pupils do not feel forced to work on a problem just because it has not been chosen by anyone else.

Mr Bowen passed out duplicated sheets to his earth science class, listing experiments on the characteristics of soils. He instructed his pupils to organize themselves in pairs and select problems on which to work. The following is the list from which they were to choose:

1. Compare the water retention in gravel, sand, and clay
2. Determine the effect of humus on water retention in sandy soil
3. Compare the drainage of sand, clay, and gravel soils
4. Compare the capillary rise of water in sand, gravel and clay
5. Compare capillarity in packed and loose clay soils
6. Determine whether water percolating through soil dissolves minerals from the soil
7. Determine the effect of lime on the structure of clay soils that are drying
8. Determine the effects of small amounts of clay on the structure of sandy soils
9. Calculate the amount of organic matter in a garden soil and a woodland soil
10. Analyze a garden soil for its sand, gravel, and clay content
11. Determine the effect of added humus on the structure of a clay soil
12. Determine the effect of added ground limestone on the pH of a soil
13. Determine the effect of peat moss on the pH of a soil
14. Determine the organic content of a top soil and the underlying subsoil
15. Test light and dark soils for heat absorption in sunlight

This approach to individualized laboratory work requires a large selection of suitable activities, closely related and somewhat equivalent in time demands. Needed materials should be readily procured. The techniques required should lie within the capabilities of the class.

Often there are, in a class, pupils who are not challenged by any of the problems stated. If these pupils have strong science interests, it may be easy to encourage them to propose their own problems even though these may not be so closely related to the topic as a teacher might think desirable. If the pupils are deterred by lack of general interest, a teacher can sometimes help them make a choice from the list by describing in some detail how a certain problem may be attacked. The vision of carrying out the activities involved may stimulate them to begin work even though they are not particularly interested in the outcomes.

Somewhat greater flexibility and initiative are possible if pupils are permitted to discover for themselves suggestions for their laboratory work.

Mr. Scarry directed his seventh grade science class to organize themselves in pairs and begin looking in textbooks for experiments on the control of fire. He provided additional references for pupils who were not challenged by the suggestions in the textbooks.

After the pupils made their selections, a planning session was held during which the pupils wrote down the materials they would need and decided who would be responsible for obtaining these materials. The understanding was that the pupils would bring most of the items from home the next morning. Actually an additional day was needed before the pupils remembered to bring everything required.

At the beginning of the next class period, Mr. Scarry gave a few cautions and set the pupils at work. He moved from group to group giving a little help but not giving any general directions. The pupils tried out their experiments and in some instances improvised variations. They demonstrated the same experiments to their classmates during following periods.

To use Mr. Scarry's techniques, a teacher must have sources of teaching suggestions. Some textbooks are excellent for this purpose. Textbooks need not be confined to a single grade level. Many seventh grade pupils can read high school texts and others benefit more from elementary science texts. The many popularized science books are excellent sources for ideas. Some teachers keep card files of experiments and allow the pupils to browse through these.

Permitting deviations from assigned work. Pupils doing assigned laboratory problems often discover interesting problems they would like to follow up. Generally they benefit more by being permitted to deviate than by being held to uniform assignments.

Bob was more interested in knowing how much material was dissolved in tap water than in determining the relative hardness of different samples of water. So while the remainder of the eighth grade group tested samples provided by the teacher, Bob began boiling down a gallon of water.

Bob took his sample home that night and continued the boiling process until a scant cupful remained. During his next science period he completed the evaporation process and ended with an evaporating dish nearly full of solids.

Bob's independent work certainly gave him a better concept of hard water than would the activities he was supposed to carry out. It is likely that the remainder of the class benefited also from his efforts.

Independent work in the laboratory is commonly an outgrowth of regular laboratory assignments. These two chemistry pupils became interested in crystal growth and are exploring the topic more deeply than their classmates.

Commonly, discoveries made by an individual pupil have great impact on the remainder of the class.

Isabelle, who had ambitions to be a nurse, brought a dead snake to her biology class. She asked that she be allowed to dissect it instead of continuing with a study of the frog. Her discovery that the snake had but one functional lung gained more attention and initiated more discussion of vestigial organs than anything the teacher had been able to present on this topic.

Independent work growing out of assigned laboratory activities generally involves one or two pupils. Sometimes, however, a large share of the class may be stimulated to work on separate problems. On page 106 is described the way Mr. Weissman used a standardized laboratory exercise on the determination of the coefficient of friction to initiate independent work on the part of most of his pupils. This technique can be applied best in situations in which moderate sized classes are made up of enthusiastic pupils. Experienced teachers who know their pupils well use this procedure with large groups.

Encouraging original research. Teachers who do not realize the possibilities for original research by high school pupils do not appreciate the richness of the science field and the capabilities of young people.

There are thousands of unsolved problems involving plants, insects, earthworms, fungi and other organisms. And even when there has already been research on a specific problem, a pupil's efforts may represent original thinking and perhaps a new approach.

Science teachers need an understanding of the limits of scientific knowledge to help their pupils find problems for original research. Thus equipped, a teacher can make suggestions that are practical for the circumstances in which the pupil must work. Unfortunately, few college courses give much attention to the limits of scientific knowledge and often give the impression that everything about familiar subjects has been completely explored. But possession of a critical attitude will help a teacher find problems that encourage pupils to do some original investigation.

Ninth grader Pat stated that exhaled breath contained no oxygen. Mr. Lowell, his teacher, criticized the statement.

Pat could find nothing on this topic in the limited library facilities so he planned an experiment to see if a candle would burn in a bottle containing exhaled breath. He discovered that a candle would burn about as long in exhaled air as in his control.

Pat's work did not contribute anything to the body of organized scientific knowledge but it did represent original thinking on his part and showed him a way to attack problems. It is equally easy to turn the attention of pupils to areas that have been practically unexplored.

Miss Appleby set up an experiment to show the effect of thyroxin on the metamorphism of tadpoles. Sally asked if thyroxin affected the development of insects. Miss Appleby suggested that Sally try its effect on some aquatic insects. After some discussion of problems of maintenance, they decided upon dragonfly nymphs as likely subjects.

Pupils may need much encouragement before they realize that they can do original research. Schools do not generally emphasize this approach to learning. But pupils will freely undertake little problems for which they can see immediate outcomes. With increased self confidence they undertake more complex problems.

Some teachers exert pressure on pupils they think capable of original work.

Mr. Gardiner operates a science fair for his own and neighboring schools. Each fall he tries to talk individually to those junior high school pupils who seem capable of meeting the standards he sets. "How about entering a project in the science fair next spring?" he asks. Sometimes he has to check on an individual several times. He is not impatient for he realizes

that these are but early adolescents who might really like to do the kind of research demanded but who think that spring, the time of the science fair, is a long ways away.

Mr Gardiner finds it necessary to suggests problems in a large number of cases He tries to provide ideas of things close to the pupils. "How does a dandelion plant grow?" "Is there any difference in the average blood pressures of children of German ancestry and of Italian ancestry?" "How does the strength of different kinds of paper compare?"

As a result of his efforts, Mr. Gardiner has in his fair a number of entries that represent work far in advance of that usually expected of junior high school pupils.

At least one teacher sets aside a block of time during which he expects all pupils to undertake independent work. Some independent work continues as original research once the pupils find they can do this type of work.

Mr. Klein includes in his plans for his general science program a "unit" during which each pupil is supposed to work on a problem of his own choosing. Many of the problems are relatively simple and some pupils fail to accomplish much but each year a few pupils are stimulated to do research that continues long beyond the time allotted to the "unit."

Ideas for original research projects may come to teachers as they are planning uniform laboratory assignments, demonstrations, field experiences, and project work. Pupils may discover problems from their science work, and from readings in books, magazines and newspapers. Both teachers and pupils can find many ideas for independent investigation at science fairs and congresses. Some pupils like to repeat work other pupils have done. Others prefer to carry out modified procedures. Sometimes a pupil finds that an approach used in one problem suggests a problem and an approach in a related field.

Pupils who do original work of this type need help in terms of laboratory facilities, released time, and advice about sources of information. Usually these pupils are superior in an academic sense and need not spend as much time on assigned work as others in their classes. They generally pass the same examinations without giving more than casual attention to the work of the class. They benefit far more from their independent work than they could ever benefit from stereotyped classroom procedures.

LABORATORY MANUALS

Many forms of laboratory manuals have been published and many teachers have taken advantage of duplication processes to prepare

their own versions. Early manuals, often bound between hard covers, were limited chiefly to giving directions for laboratory activities sometimes accompanied by brief discussions of procedures and by suggestions for reporting data. Many manuals today are of the "disposable" type and strongly resemble workbooks; these manuals contain provisions for reporting data—tables to be filled in, sentences to be completed, diagrams to be labeled, spaces for sketches, facilities for making graphs.

Laboratory manuals are unquestionably time savers. The teacher is freed from the preparation of directions for each laboratory period. He need not use class time for giving directions. Pupil time is saved because the directions have been worked out so carefully that positive results can be obtained without fumbling. And if a manual with record forms is used, pupils need spend little time organizing and reporting data.

On the other hand, laboratory manuals are not necessarily efficient even though laboratory work progresses more rapidly. Manuals tend to stereotype the laboratory program. They work towards uniform outcomes and do not provide for pupils with special interests and abilities. Commercial manuals cannot recognize purely local resources and needs.

The activities proposed by laboratory manuals are commonly "verification" type exercises rather than true experiments. The manuals make little or no provision for independent thinking. Pupils are expected to follow directions carefully to attain results, but they may do so blindly. Pupils gain little practice in formulating problems, planning methods of attack, assuming responsibilities for their work, criticizing their data, and drawing justifiable conclusions.

Pupil reaction to laboratory manuals is varied. Some pupils like definite assignments which need only to be carried out carefully to obtain success. Others like the forms for reporting data because they need not concern themselves with the type of organization to be used. However, some pupils fret at the lack of freedom; they find no challenge in working towards outcomes they recognize in advance.

Use of laboratory manuals may be justifiable in some situations. Teachers with exceptionally heavy teaching loads must look for all types of labor saving devices. A chemistry teacher with six sections of thirty pupils each undoubtedly needs some type of manual, either a commercial form or one prepared by himself. He could not keep up with his work otherwise.

A beginning teacher who has had little training in the subject assigned to him may find needed security in a manual. His background does not provide him with a knowledge of tested activities. His in-

experience handicaps him in recognizing and taking advantage of situations that arise during his teaching.

A laboratory manual is also useful for pupils who must work under self-direction, such as those making up work lost by long periods of illness.

However, laboratory manuals must not be allowed to dominate the science program. Teachers who for one reason or another are dependent upon them should work towards the day when they are free to use them only for the special contributions they may make.

Suggested activities

1. Begin making a card file of suggestions for laboratory experiments and exercises in the major science areas, giving preference to those that require materials that are inexpensive and easily procured in quantities. Include a list of needed materials with each activity.
2. Prepare a direction sheet to guide pupils during a uniform laboratory exercise.
3. Plan a simple laboratory exercise. Procure the necessary materials, and administer the activity to the others in your science methods class. Afterwards ask for criticisms.
4. A distinction should be made between a stereotyped laboratory exercise and a true laboratory experiment. Plan and carry out a true laboratory experiment of the type suitable for secondary school pupils. Report your findings to your methods class for criticism of your procedures and your conclusions.

Suggested readings

Brandwein, Paul F., "Some Suggestions for Individualized Work in General Science and Biology Laboratory," *School Science and Mathematics*, November, 1945.

Manwiller, Lloyd W., "Laboratory Activities—Why?" *School Science and Mathematics*, February, 1956.

A Program for Teaching Science, Thirty-first Yearbook of the National Society for the Study of Education, Part I, Public School Publishing Company, Bloomington, Ill., 1932.

Science Education in American Schools, Forty-sixth Yearbook of the National Society for the Study of Education, University of Chicago Press, Chicago, 1947.

"Science in General Education," Report of the Science Committee of the Commission on Secondary School Curriculum of the Progressive Education Association, Appleton-Century Company, New York, 1938.

Science in Secondary Schools Today, Bulletin of the National Association of Secondary School Principals, Volume 37, Number 191, Washington, January 1953, Chapter III.

chapter 6 DEMONSTRATIONS OF ALL KINDS

Demonstrations are very useful teaching devices. They serve several possible functions, often two or more at the same time. Generally, teachers should use demonstrations more freely than they do, but it must always be remembered that demonstrations have certain limitations. Demonstrations should not be used indiscriminately nor to the exclusion of other teaching techniques. Improperly used, they defeat the purposes of the science program. Used to the exclusion of other techniques they prevent the full realization of the potentialities of the science program.

CHARACTERISTICS OF DEMONSTRATIONS

A demonstration is, as the word implies, a showing. When a teacher shows his class how to cut a pane of glass he is presenting a demonstration. When he shows the reaction of sulfuric acid and sugar he is presenting a demonstration.

Many demonstrations are called "experiments" when according to the strict meaning of the latter term they should not be. To be an experiment, a demonstration must be built about a problem the solution of which is unknown to the pupils. The teacher who demonstrates the electrolysis of water to show that water is composed of oxygen and hydrogen is *not* performing an experiment. The teacher who demonstrates electrolysis of water to find out what constitutes water *is* performing an experiment. There is a subtle but important difference.

By custom, demonstrations are presented by teachers. There are many valuable outcomes to demonstrations presented by the pupils themselves, either acting alone or in small groups. To profit by these possible outcomes the teacher should broaden his concept of demonstrations to include pupil presentations.

Special functions of demonstrations. Demonstrations may be used in several ways, each of which makes its own special contributions to the teaching of science.

1. *To set a problem.* A demonstration may be presented without previous discussion. From the results arise problems of interest to the class.

Mr. Cassidy used the traditional "water to wine" trick to introduce a study of chemical indicators. As he poured water containing a little phenolphthalein from a bottle into a drinking glass containing traces of sodium hydroxide, the liquid became bright pink. The startled pupils demanded to know the cause and thus the topic was introduced.

2. *To illustrate a point.* This is the most common use of demonstrations.

During a discussion of a recent eclipse of the moon Miss Appleby set up a model to demonstrate the relative positions of the sun, earth, and moon during an eclipse.

3. *To help solve a problem.* Sometimes a problem of general interest arises quite spontaneously. If the answer can be discovered by an experiment that lends itself to demonstration, it may be advantageous to employ this technique.

During a discussion of safety practices the question about the electrical conductivity of water arose. Mr. Knuth needed but a few moments to assemble the equipment needed to provide an answer to the question.

4. *As a review.* After pupils have carried out an experiment or have seen one performed, a follow-up demonstration of the same or closely related experiment makes an excellent review, usually much better than an oral review.

A chemistry class had tried copper plating by electrolysis during a laboratory period. Two weeks later during a discussion period Mr. Wexler set up the same materials. As the experiment was in progress Mr. Wexler asked questions about the reactions involved. Several pupils were able to clear up points that had confused them and all pupils understood the process better.

5. *To serve as a climax.* An exciting demonstration is an excellent way to end a unit.

Mr. Kuhn regularly ended a general science unit on the nature of air with a demonstration of the preparation of oxygen and the combustion of such chemicals as sulfur and magnesium in an atmosphere of pure oxygen. At the close of the demonstration he explained that this activity is typical of the work done in high school chemistry.

Some advantages of demonstrations. Demonstrations have several advantages that make them highly favored as teaching devices.

1. A demonstration guides the thinking of all the pupils into approximately the same channels. Problems may be raised and defined, solutions may be proposed and tested, and conclusions may be drawn, all as a class activity. If the subject has been carefully chosen and if the situation is properly developed, all pupils gain approximately the same understanding. It must be pointed out, however, that the technique of getting all pupils to participate fully is far from simple.

2. A demonstration is economical of materials. Some items are too expensive to buy in quantities. For example, the mercury needed for barometers, and the vacuum pumps needed for atmospheric pressure experiments are very expensive. Other items may be too delicate to put in pupil hands. An example of this is the Hoffman apparatus used for electrolysis of water.

3. Demonstrations enable a teacher to utilize activities that would be too dangerous for pupils to carry out themselves. Work with high voltage condensers is typical of such an activity.

4. A demonstration may be economical of teacher time and energies. It is simpler to prepare material for one experiment than for fifteen duplicate experiments. It is easier to perform one experiment than to supervise fifteen. And it is much more convenient to store the materials needed for one demonstration than for fifteen experiments. However, the objectives of the science program must not be neglected in the interests of economy. If the substitution of demonstrations for individual experiments results in lessened interests and understandings, the savings in time and energy may actually be expensive.

5. A demonstration may be economical of class time. Materials used for a demonstration can often be set up and tried out before a class period begins. The teacher, being experienced, can perform the demonstration more smoothly and more quickly than the pupils. On first thought, demonstrations might seem to be the most efficient way of teaching. But the very smoothness and swiftness of the pace of a demonstration may defeat the ends desired. A demonstration seen is not necessarily a demonstration understood.

The limitations of demonstrations. Demonstrations have several serious limitations that make them useful only for certain types of learning situations.

1. Visibility is always a problem. Pupils must be able to see all details of the apparatus being used and all details of the reactions that take place if they are to profit by a demonstration. Visibility is a much more serious problem than most teachers realize.

Miss Coleman, wearing a bright red dress, set up an air thermometer to show the expansion of air when heated. To make the liquid visible she colored it with red ink. But when she stood behind the apparatus, the red liquid was almost completely invisible against her red dress.

2. Pupils have little opportunity to become familiar with the materials. The apparatus may be presented already assembled or may be assembled so rapidly that relationships cannot be grasped. Elements that are simple alone may appear complex in combination. Irrelevant items often distract attention.

To demonstrate the action of a photoelectric cell, Mr. Johnson assembled on his demonstration desk the following materials: a step-down transformer, a light source with condensing lenses, a photoelectric cell in its housing, a vacuum tube amplifier, a sensitive relay, a rectifier, and an electric bell. The pupils enjoyed the demonstration but they considered the topic difficult to understand.

3. Much scientific information cannot be grasped adequately by sight and sound alone. Odors require close-up observation. Texture is best determined by touch. Forces are more significant when muscular action is involved.

4. A demonstration is apt to go at such a rapid pace that pupils do not grasp each step. Unfortunately many pupils are reluctant to raise questions when they fail to follow the steps in a demonstration.

Mr. Jones used a large scale model to explain the action of the commutator in a direct current generator. After he turned to another topic, a girl, somewhat timidly, raised a question about the commutator. Mr. Jones in evident exasperation returned to the first topic. Upon questioning he discovered that a large share of the class had not grasped the concept of the alternations of current in the rotor and had understood little about the purpose of the commutator.

5. During any discussion which results from a demonstration, there may be instances when certain pupils tend to "carry the class along," to the detriment of the others. It is not unusual for a few pupils with

special interests or abilities to dominate the discussion, leaving the remainder of the class to flounder along or to drop by the wayside.

6. There are few opportunities for active pupil participation during a demonstration. It is difficult to insure complete mental participation while the body remains inactive. In consequence, attention is readily distracted by irrelevant influences both internal and external to the pupils. Such loss of attention, unless accompanied by disturbance, may go unnoticed by the teacher.

7. Elaborate demonstrations tend to be too convincing. The use of professionally-made apparatus, in particular, adds a note of authority and makes the results difficult to question.

Mr. Reeves fastened a large U-shaped electromagnet to a hook in the ceiling of the physics classroom. When the science period began he energized the magnet, mounted a stepladder, attached a steel ball to one pole of the magnet and a cork ball containing a tack to the other pole. Then he descended and de-energized the magnet. The two balls, falling through a distance of about twelve feet, seemed to land at the same time. No one in the classroom questioned the conclusion that heavy and light objects fall at the same rate.

PLANNING A DEMONSTRATION

A demonstration is "produced" much as a play is produced. Attention must be given to many of the same factors as stage directors consider—visibility, audibility, single centers of attention, audience participation, contrasts, climaxes.

Preliminary considerations in demonstrating. The first thing that should be considered when planning a demonstration is whether a demonstration, with all its limitations, is the best way to deal with a certain topic. It would be poor technique, for instance, to use demonstration procedures in testing foods for starch when individual experimentation could be so much more effective.

A second consideration is whether the subject material lends itself to the demonstration technique. Are there, for instance, elements of suspense? Will the action move along with sufficient speed? Is there adequate variety within the procedures to maintain interest? Is there a satisfactory climax? Must there be long periods of inactivity while waiting for water to boil or for liquids to filter out?

A third consideration is whether or not the materials being utilized can be made visible to each pupil in the room. A demonstration is worse than useless if pupils do not know what is occurring.

During the consideration of any demonstration it must be remembered that the primary objective of the lesson is to bring about important changes in the pupils. A demonstration should be presented, not because it fills in a gap in some conventional and arbitrary organization of subject matter but because it may result in real benefit to the pupils.

Insuring visibility. Simple, large scale apparatus is best for demonstration purposes. When small items must be used, there should be special provisions for making them visible, perhaps by some form of projection. Even when large pieces of apparatus are used, consideration must be given to making small but important details visible.

The position of materials on the demonstration table may be critical. There are often blind spots on a standard demonstration desk. Some of these blind spots are due to the relative positions of the pupils and the table. Some are due to materials which are placed on the table. The only way to avoid these blind spots is to view the demonstrations from the seats that the pupils will be occupying.

The background behind the apparatus is important. A dingy, half-erased blackboard makes the worst possible background. Large sheets of white or colored cardboard, or backdrops of cloth, together with suitable supports, are valuable in demonstration work.

Contrasting colors within the apparatus itself helps to distinguish the various elements, but care should be used lest these colors detract from reality or give incorrect concepts.

Proper lighting is also essential. Too often demonstration materials are inadequately lighted. Contrasts may be too low. Or there may be disturbing highlights, such as the reflection of windows from glassware, which obscure the contents of the vessels.

Backlighting to silhouette apparatus may be useful. A brilliantly lighted white backdrop behind unlighted apparatus increases the contrast between opaque and transparent objects. A similar effect can be obtained by setting apparatus on a window sill. This technique is especially effective for showing action inside glass containers.

One or two spotlights properly focussed on demonstration apparatus make a startling difference. In some modern schools spotlights are built into the ceiling above demonstration desks. These provide good top lighting. Sidelighting is effective in many instances. Color filters may be used with spotlights for dramatic effects.

Demonstration materials need not always be placed on a demonstration table. Materials placed on the floor or on low tables enable pupils to look down on them. Materials suspended from the ceiling

permit an upward view. Large scale materials may be set up outdoors where pupils may walk around them.

Focussing attention on the demonstration. An uncluttered setting focusses attention on the important details of a demonstration. Often it is wise to begin a presentation with a completely bare table. As each item is needed it is taken from a box, a drawer or a convenient cupboard.

An element of suspense is introduced if the materials are kept in a box whose contents are not visible to the pupils. The pupils keep wondering what next will be withdrawn and how it will be utilized.

If a large piece of apparatus must be assembled beforehand, it may be covered with a cardboard carton. As the apparatus is "unveiled" it is certain to attract attention.

Another technique for attracting attention is to set in operation some device that pupils will notice as they come into the classroom.

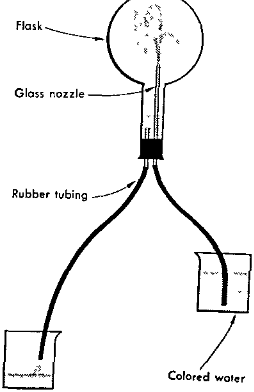

FIGURE 3. *A fountain in a vacuum. This attention-catching device is in reality a siphon. Atmospheric pressure forces the colored water up into the low pressure region in the flask, from which the water drains into the lower container. The fountain is started just as is the flow in a siphon.*

One day when Mr. Goff's pupils came into their classroom they saw the scientific novelty which Mr. Goff later termed a "fountain in a vacuum" (see figure 3). A bright red liquid was jetting upwards in a large flask, seemingly of its own volition. The first few pupils who noticed it began to discuss it and soon most of their classmates were clustered around, trying to account for its behavior.

Planning for variety in demonstrations. As in all other phases of work with boys and girls, variety in using demonstrations is desirable. Variety can be achieved by modifying basic techniques slightly. Each modification may have an entirely different effect on the pupils.

Variety can be provided by using different techniques of presentation, by utilizing special apparatus, by using different demonstrators, by taking advantage of situations that arise spontaneously, and by varying the setting of the demonstration.

1. The teacher may present a previously prepared demonstration. This is the type most commonly seen in science teaching and needs no description.

2. The teacher acting on the suggestions of the pupils may set up and present a demonstration to solve a problem that has arisen in discussion. To be effective, such demonstrations require immediate access to demonstration materials.

3. A pupil may present a previously prepared demonstration. The pupil may have set up the materials after school, at home, or during time allotted from the class period. Unless the pupil is exceptionally able, it is wise to keep such demonstrations simple and direct.

4. A group of pupils may present a previously prepared demonstration. This group may have worked after school or during time allotted from the regular class period. The subject should be simple and direct.

5. A pupil may carry out a demonstration under the direction of the teacher. In this situation a pupil has no idea of what he will be doing until he is given oral directions from the teacher. Again the subject of the demonstration should be simple and direct, but a number of pupils in succession may be directed to carry out a series of related demonstrations.

6. An outsider—a pupil from another room, another teacher, or an expert not connected with the school—may present a demonstration. Demonstrations by outsiders are often difficult to control and may be too difficult for the pupils to follow. Adults who are not trained in teaching are particularly apt to go too fast, to fail to give basic understandings, and to depend upon a technical vocabulary.

7. A demonstration may be presented with some special piece of apparatus such as an opaque projector. The use of unusual apparatus adds novelty and a bit of suspense.

8. A demonstration may be presented in some new setting such as outdoors. Although there are special problems in these demonstrations they are very effective in capturing and holding attention.

9. A demonstration may involve spectacular noises, lights, or motions. The occasional use of such devices is justified in terms of attention and favorable attitudes.

The importance of preparation and pre-testing. Last minute preparations are apt to result in confusion and embarrassment. If a teacher

Mr. Kimball displayed a wooden disk and a brass ring of the same diameter to his physics class. With a balance he showed that the two items weighed the same. Then he held the two at the top of an inclined board.

"Which one will roll down the slope faster?" he asked the class.

Some pupils thought the disk would roll faster while others thought the ring would reach the bottom of the incline first. Most of the pupils, however, thought that the two would roll at equal speeds.

Interesting problems can arise from the action of the demonstration materials themselves. From the problems the pupils discover the purposes of the demonstrations.

Before her class convened, Miss Parry clamped one end of a copper tube to a laboratory support. The other end of the tube almost, but not quite, touched another support. Wires connected the supports to a dry cell and electric bell.

In presenting her demonstration, Miss Parry directed a pupil to heat the copper tube with a gas burner. In a few moments the bell began to ring and then later, after heating was ended, it stopped.

The pupils speculated on the reasons, one suggesting that the heat produced electricity, a suggestion that was shouted down because of the presence of the dry cell, and another pupil suggested that the metal became a better conductor when heated. Miss Parry acknowledged the contributions and then directed a pupil to trace the circuit. The gap was discovered, a new hypothesis was raised, tested and verified.

Some teachers have the unfortunate habit of telling their pupils in advance what the outcomes of the demonstrations will be. Occasionally the practice is justified but whenever it is used it denies pupils opportunities to formulate their own problems, to speculate, to plan methods of attack, and to draw conclusions in terms of their findings.

Acquainting pupils with materials and procedures. Much has been said about the need for making demonstration materials visible. Equally important is the need for helping pupils recognize the materials being used and the function that each item plays in the demonstration.

The first two items Miss Carpenter drew from a box were a spark plug and a "hot shot" battery, both of which the pupils identified. Two pupils connected the plug to the battery without producing a spark.

The third item was a spark coil which Miss Carpenter identified. Two other pupils connected this to the plug and battery following a circuit diagram Miss Carpenter drew on the chalkboard. This time a spark was produced.

The fourth item was a friction-top metal can in which a hole had been made to hold the spark plug. Pupils succeeded in producing a spark inside the can.

The fifth item was a bottle of gasoline, a few drops of which Miss Carpenter used in blowing the lid from the can.

During this demonstration, Miss Carpenter made no assumptions about the understandings of her pupils. She made sure that each item was identified and its purpose made clear.

During demonstrations that involve several steps or several associated activities it is usually well to stop occasionally for summaries of results. Such results may be given orally or they may be recorded in tabular form on the blackboard. The recording of results in the form of graphs is also helpful.

Pacing a demonstration. The audience must not be forgotten during a demonstration. Facial expressions, obvious inattention, questions, laughter and exclamations—all these are helpful clues in judging the effectiveness of a presentation.

A teacher should remember that it is difficult for young people to sit quietly for any great length of time. He should provide opportunities for relaxation. In general, it is best for demonstrations to be short and fast moving. If a demonstration must be extended over a considerable period, it may be possible to break it up into various phases separated by brief intervals during which pupils engage in other activities.

Suspense is a useful device for holding attention. The moments leading up to a dramatic climax—an explosion or the fracture of a loaded wire—can be very exciting. Races of various types have their moments of suspense.

Humor can play a part, too. Laughter is an excellent way to relax tensions. Adolescents tend to favor absurd situations and many demonstrations can be devised to end with ridiculous outcomes.

In so far as possible pupils should be permitted to participate physically in demonstrations. There are relatively few situations in which the teacher must do all the manipulation and even then pupils can often serve as assistants. It is usually possible for first one pupil and then another to carry out certain phases of a demonstration under the direction of the teacher.

Insuring understanding of events. Things are apt to happen so rapidly in demonstrations that a pupil misses some of the important points. He may have had a momentary lapse of attention, his vision may have been blocked at a critical moment, or an exclamation may have drowned out an essential word. If he dislikes calling attention to

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All equipment used in demonstrations should be large enough to be plainly visible to each pupil. The pupils above are illustrating the principle of the thermostat with large scale materials. Their teacher commonly employs pupils in demonstrations and stays at one side where he can judge the effectiveness of the presentation and give advice. This practice also gives pupils valuable experience.

directions without predicting results. It demands that he ask questions that encourage careful observations and intelligent speculation without telling pupils what they are to see or what conclusions they are to draw. It demands that he be critical of pupil statements without letting himself be influenced by what he thinks they should say.

The "hands in pockets" technique has certain advantages. It frees the teacher to move about the classroom to notice how pupils react, to give help here and encouragement there. He is better able to check on visibility and audibility. He can see whether all pupils are responding desirably.

Mr. Jones set a carton on his demonstration table and took from it a box of baking soda, a bottle of vinegar, a spoon and a drinking glass.

"Has anyone done an experiment with these four things?" he asked. Several hands went up.

"All right, Bob," he said to one of the boys. "Come up and show us what you have done."

As Bob came forward, Mr. Jones moved to the side wall out of the center

his failures he may say nothing and thus fail to grasp the significance of the demonstration.

A teacher should utilize all possible techniques to help pupils keep abreast of events. One such technique is to ask a pupil to describe what he saw and then, without signifying approval or disapproval, to ask another pupil if he made the same observations. If arguments result, it may be necessary to repeat all or part of the demonstration.

Pupils are not always sure of the procedures used even when a teacher has used utmost care in describing them. Brief reviews may help these pupils to clarify their thinking. A review may be broken into several parts with one pupil reiterating the purpose, another describing the materials, and still another giving the procedures.

Summaries, both oral and written, are essential. When demonstrations are made up of a number of distinct phases, interim summaries are desirable. Whenever possible, data should be summarized in chart or table form on the blackboard. This is often done by a class secretary.

If materials or products which result from a demonstration need to be examined or handled by the pupils, these may be passed out to the class in duplicate, or labelled properly and exhibited for later examination.

Working towards general objectives. No matter how valuable the subject matter outcomes of a demonstration may be, equally important are the physical and mental changes which have been brought about in the pupils through their participation in the activity. Because mere passive acceptance of results produces few changes, pupils need maximum opportunities to manipulate materials, to perform before the group, to speculate about possible results, to defend viewpoints, and to modify opinions when presented with contrary data.

A teacher can well afford to adopt a "hands in pockets" attitude, both literally and figuratively, in all his teaching, demonstrations included. Each time a teacher manipulates materials that pupils should manipulate, each time he gives pupils an answer to a question that they could solve themselves, each time he forces a ready-made opinion upon his pupils, he is denying them the opportunities to benefit fully from his teaching.

The technique of keeping one's hands in one's pockets, both physically and mentally speaking, is not an easy one to master. Tradition makes the teacher a fountainhead of all wisdom and common teaching practice encourages a teacher to dominate classroom activities. But habits can be broken and tradition can be ignored.

The "hands in pockets" technique demands that a teacher give

It is not uncommon to find a teacher beginning a demonstration only to discover that the pupils have already seen the demonstration previously. It is not always necessary to discard one's plans if such an incident occurs. Sometimes the same demonstration can be used to illustrate a more advanced idea.

Miss Hull planned a "candle race" for her seventh grade class to find out whether the size of a jar covering a candle affected its burning. The pupils protested that they had watched the same demonstration the year before.

"Let's try it anyway," Miss Hull said and appointed three pupils to handle the jars, and another pupil as timekeeper. As expected, the candle under the smallest jar went out first.

"Can anyone tell why this happened?" Miss Hull asked. The first responses were the usual ones—"air used up" and "oxygen used up." Then pupils began to speculate about carbon dioxide and heating effects. Miss Hull proposed that they try the experiment again to see if they could discover any clues as to the correct answer.

This time, to everyone's surprise, the candle under the smallest jar burned longest! On a third trial all candles went out at once! The effect was more speculation, more hypothesis formulation, and more attempts at verification.

Eventually the pupils understood. Miss Hull had carefully lifted the larger jars from the extinguished candles and had placed them, mouth down, on the table top. But during the second trial she had held the smallest jar in her hands inconspicuously while the pupils were talking, thus interchanging the air inside.

Sometimes a teacher can anticipate undesirable reactions from his pupils and plan demonstrations to startle these pupils into more favorable ways of thinking and acting.

Two boys in Mr. Pratt's physics class had an annoying "know-it-all" attitude that disturbed the smooth operation of the classroom. They reacted as expected when Mr. Pratt exhibited a Cartesian diver, in this case a miniature test tube floating inverted in a glass cylinder.

Mr. Pratt asked one of the boys to explain the diver, which he did creditably enough. He then asked the boy to demonstrate it. But the diver refused to cooperate. The diver behaved properly for other pupils but not for the two boys.

The remainder of the class was at first quietly amused but became boisterous when the diver began a series of strange antics. The diver would continue to float while pressure was applied but sink when pressure was released. Once the diver bobbed up and down insultingly as soon as a pupil had turned his back.

of attention. After Bob had demonstrated the action of vinegar on baking soda, Mr. Jones invited a pupil who had never tried the experiment to come forward and carry out the same activity.

Mr. Jones took other things from his box—a lemon, a tomato, a can of grapefruit juice, a box of alum—and in each instance asked for suggestions for experiments The pupils proposed the things to do, carried out their suggestions, and kept records on the blackboard.

During this lesson Mr Jones did no manipulation save to take items from his box, and he gave no information save to introduce the word "react." His hands were in his pockets, figuratively speaking, at all times. The pupils proposed most of the things to do and they learned by making their own discoveries. They ended the lesson with a limited but valid generalization that could serve as a basis for more extensive work.

This lesson illustrates other important points. It moved swiftly and with several different approaches. There were moments of suspense in waiting to see what would happen, and satisfactory climaxes when the solutions bubbled over the top of the glass. The closed box produced a feeling of anticipation. Best of all, there was opportunity for most of the pupils to participate actively at one time or another during the period.

Some special presentations. There are several general patterns for demonstration procedures and each pattern is capable of infinite variation. The more that a teacher can adapt general procedures to fit special circumstances, the closer he can come to meeting the goals he has set up for his program. This often calls for considerable ingenuity.

One situation that may be encountered is the need to discuss with pupils the characteristics of certain specimens.

Mrs. MacWilliams found that the pupils in her earth science class were having difficulty distinguishing between gneiss, schist, and some of the banded sandstones. She planned to discuss the characteristics of some of the different gneisses with her class but she wanted to call attention to characteristics that could be seen only in large specimens and to characteristics that could be seen only on close examination.

She prepared several large specimens of the gneisses, each a foot or more across. She also prepared fifteen sets of chips from these same gneisses, each numbered to correspond with the large specimen from which it came. She was able to point out characteristics on the large specimens placed on a table in front of the group. She was also able to refer to characteristics in the small specimens by referring to each by number.

readily to forces of less than a gram. This balance may be used to show the changes in weight of air as it is being heated and to compare the densities of carbon dioxide and air.

2. *Atmospheric pressure.* Demonstrations of atmospheric pressure require a vacuum pump, which may be either hand or electrically operated, a pump plate, and an assortment of bell jars. To show pressure changes, a direct reading dial-type pressure gauge is desirable.

3. *Submerged and floating objects.* The best device for showing what happens under water is a large, rectangular aquarium. An aquarium should be reserved for this purpose alone.

4. *Chemical reactions.* Glassware for chemical demonstrations should be big. Specific gravity cylinders and gallon battery jars make good test tubes for cold reactions. When heat is involved, oversized test tubes and large flasks are needed.

5. *Electric currents.* A large scale galvanometer is needed for demonstration work in electricity. The model pictured on page 144 is excellent. It has an added advantage in that suitable shunts and series resistances placed in the circuits convert it to a voltmeter or an ammeter as desired. The scale is visible at a considerable distance.

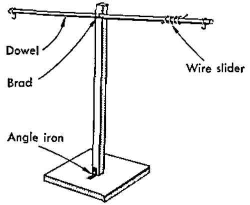

FIGURE 4. *This diagram shows details of construction of a simple balance. The beam is a quarter-inch dowel thirty inches long; the upright is about thirty inches long, and the base, a foot square. The hooks are made of #24 copper wire. A spiral of wire serves for a rider. Counterbalance weights can be made from loops of wire.* (From Walter A. Thurber, "A Demonstration Balance," *School Science and Mathematics,* April, 1941.)

6. *Temperature changes.* Suitable equipment for demonstrating temperature changes by direct reading instruments is not available for secondary school teachers. In college demonstration work, elaborate thermocouple and galvanometer combinations are used, but these are obviously too complex for general science and probably not desirable for physics and chemistry.

Direct readings can be made from dial-type immersion thermometers but the dials are too small to be read at a distance. To show temperature changes the air thermometer shown in figure 5 provides fair visibility but no readings. Unfortunately the air thermometer does not resemble a standard liquid thermometer and pupils must become

Mr. Pratt revealed the secret. The inverted test tube was weighted with a ring of iron wire. Under the table top was a strong electromagnet. When Mr. Pratt pressed his knee against a button he could make the diver descend independent of any pressure applied.

Novelty in demonstration serves to attract and hold interest. Novelty also makes classwork more enjoyable.

Mr. Martin entered the general science classroom a few moments late. Without a word he picked up a ball-and-ring apparatus and showed that the ball could pass through the ring, weighed the ball, and entered the information on the blackboard. His very silence began to attract attention.

Mr. Martin heated the ball, showed that it could no longer pass through the ring, weighed it again, and entered this figure beside the other one. He wrote on the board "What is the purpose of this experiment?" and then left the room.

The pupils who had been merely puzzled before now began to argue. After a few moments of confusion one boy took charge of the class, appointed a secretary, and by the time Mr. Martin returned a few minutes later, had guided the class in making a record of the experiment.

SPECIAL EQUIPMENT FOR DEMONSTRATIONS

Special teaching techniques usually require special equipment. Demonstrations are no exception. Sometimes a teacher needs basic apparatus that he can assemble to meet his needs, then take apart and reuse in other demonstrations. Sometimes he needs apparatus specially designed to emphasize a point or set of related points.

Multi-purpose equipment. Apparatus that can be used in many different demonstrations includes the following:

1. *Demonstrations involving weight and other forces.* Scales with large dials are a necessity for comparing forces. Platform scales of the spring type are excellent for weighing objects and determining downward forces. Dairy scales, designed for weighing pails of milk suspended from them can be used to determine both weights and other forces.

It is desirable to have two of each type so that comparative readings can be taken simultaneously. Two platform scales, for instance, may serve as the piers of a model bridge to show the change in forces as a loaded toy truck moves across the bridge.

To indicate slight changes in weight, a sensitive balance is needed. Figure 4 gives details for building a demonstration balance that reacts

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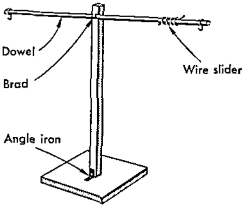

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To indicate slight changes in weight, a sensitive balance is needed. Figure 4 gives details for building a demonstration balance that reacts

Fred was in the process of "junking" an automobile when he asked his general science teacher to help him understand the differential. While the teacher was explaining, Fred recognized the need for a model and proposed making one. He removed the differential gears from their housing and make a wooden framework to hold them. He sawed off a drive shaft and attached a crank for turning the gears. He sawed off the axles and attached disks of plyboard to simulate wheels. By the time he had completed the model he understood differential action himself and had helped some of his classmates understand it. Incidentally, the teacher gained a valuable piece of demonstration apparatus.

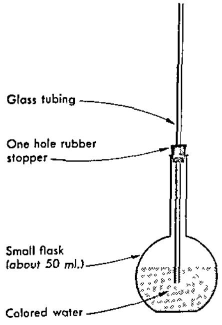


FIGURE 5. *An air thermometer.*

More commonly pupils need ideas for constructing apparatus. They may follow directions given in a professional journal or adapt ideas given in a photograph. Sometimes they need only the description of a device seen by or conceived by their teacher.

Mr. Hall needed a device to demonstrate the nature of reflected colors. He told three pupils about the apparatus he had in mind. In a short time they had produced the device shown in figure 6. For a light source they used

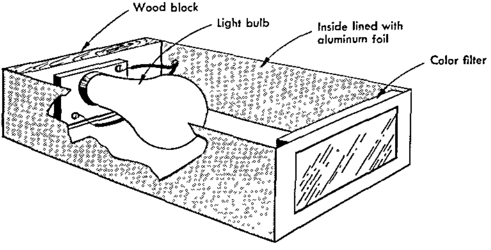
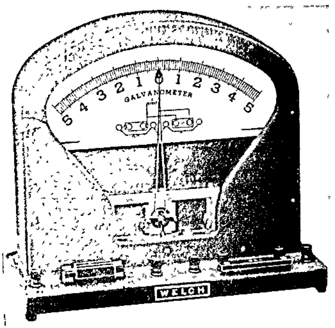


FIGURE 6. *A demonstration color-mixing box.*

thoroughly acquainted with its behavior before it can be effectively used in demonstrations.

Building special apparatus for demonstrations. Science teachers have opportunities to display a great deal of ingenuity in the construction of apparatus for their demonstrations. Professional literature contains many examples of intriguing, exciting, and instructive devices.



A demonstration galvanometer.

The advantages of these teacher-constructed devices are several. Most important is the fact that they are designed to illustrate a specific point that the teacher wishes to emphasize. Thus they fit into his teaching plans and correspond with his patterns of instruction. A teacher uses these devices with a special flair because he is so well acquainted with them, and with a special enthusiasm because he has created them himself. His pupils respond to this personal interest in the materials.

Added advantages result when pupils construct demonstration apparatus themselves. They benefit directly from the experiences of planning and construction, and from the presentations they make. Their classmates benefit by increased interest.

Teachers may suggest demonstration equipment for pupils to make. Pupils will also make suggestions themselves.

sciences where pupils are more used to thinking in abstract terms than are pupils in general science.

Presentations involving miniature materials. Sometimes it is desirable to use miniature materials during demonstrations. Then special procedures must be developed so that all pupils can see the materials involved.

Microprojectors may be used for such microscopic materials as thin tissues and one-celled organisms. Since the viewing is somewhat unreal, it is best if pupils have had an opportunity to view the same or similar materials through a microscope beforehand.

Mr. Shaw's biology pupils had already prepared and viewed slides of paramecia from a hay infusion. To introduce amoebae, Mr. Shaw prepared a slide of several of these organisms and projected it with a microprojector. The class was able to view some of the characteristics of amoeboid movement and structure. Afterwards, interested pupils tried to find amoebae for further study.

A standard $2\frac{1}{4}$ by $4\frac{1}{4}$ slide projector can be used to project thin materials such as leaves in silhouette, or to show some details of structure of specimens that are sufficiently translucent.

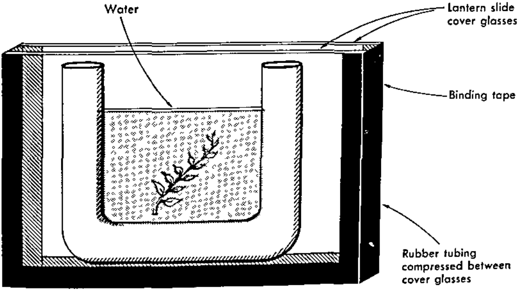


FIGURE 8. *Water cell for the projection of small aquatic organisms, chemical processes, and the like, with a standard lantern slide projector.*

A water cell can be made for the same type of projector. A short length of rubber tubing is arranged in "U" shape between two glass slides and the whole is clamped tightly with tape (figure 8). Liquids

a shoe box lined with aluminum foil and fitted with a lamp socket on a block of wood. For filters they used several thicknesses of colored cellophane sandwiched between panes of glass. They used the colored light to illuminate sheets of colored construction paper to see how each type of paper appeared in light of different colors.

Demonstration apparatus tends to fall into two general categories—those used to illustrate the workings of some commonplace devices and those used to illustrate certain scientific principles. Fred's model of the differential falls in the first category. The following is an example of the second:

Figure 7 shows a device used by Mrs. Borodino to demonstrate to eighth grade pupils that the strength of an electromagnet depends upon the number of turns in the coil and upon the current flowing through the coil. The two electromagnets, made from stove bolts wound with insulated wire, are connected in series so that the same current goes through each. They are mounted in a frame to improve visibility.

Pupils determine how many paper clips each electromagnet is able to hold when a single dry cell is used. They then repeat the experiment using two dry cells. The ammeter is used to indicate the change in current.

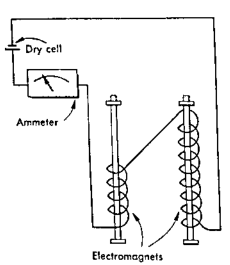


FIGURE 7. *A device for demonstrating that the number of turns of wire on an electromagnet determines the strength of the magnet.*

Demonstration apparatus should be designed to be as simple and straightforward as possible. It is very easy to introduce confusing elements while attempting to emphasize certain points. Even with Mrs. Borodino's excellent device for illustrating the principles of electromagnets it should not be forgotten that many pupils do not realize that the current is the same in both electromagnets.

Pupils generally understand apparatus that is closely related to things with which they are familiar. A device for showing the effect of tension on vibrating strings can be made similar to a guitar or banjo. Models of cranes and slide projectors are usually effective.

Apparatus used to demonstrate abstract principles, however, may be less readily understood and are more appropriate for the advanced

Four pupils from Mr. Hull's ninth grade science class prepared a demonstration as part of a unit on aerodynamics. They suspended two flasks about an inch apart, hanging them from strings attached to an overhead support. During the demonstration one of the pupils blew through a long glass tube pointed at the space between the flasks. The action of the flasks was made visible by projecting greatly enlarged shadows of the apparatus on a beaded movie screen.

Audibility is as important as visibility in many demonstrations. Sounds can be picked up and amplified by means of a microphone, an amplifier, and a loud speaker.

Mr. Shippley placed a microphone on a pupil's chest and amplified the sound of his heart beat with the sound projection apparatus of a sound movie machine. He was able to point out the nature of the different sounds and he was able to demonstrate the effects of various conditions such as exercise. Later he purchased a special stethoscope-microphone which gave more satisfactory results.

Suggested activities

1. Make a check list of points to guide you during the presentation of a demonstration. Observe a science teacher present a demonstration and apply your check list.
2. Prepare a demonstration and present it to your methods class. Afterwards ask for criticisms.
3. Prepare a demonstration that pupils would be able to present by following your oral directions. Carry out this demonstration using the members of your science methods class to gain practice in this technique.
4. Continue to build up your activity card file by adding suggestions for demonstrations.

Suggested readings

Brown, H. E., "Materials for Laboratory and Demonstrations," *Science in Secondary Schools Today,* The Bulletin of the National Association of Secondary School Principals, Volume 37, Number 191, January 1953, pages 117-122.

Bruce, Guy V., *Experiments with Water, Air, Fuels, Heat, Magnesium and Electricity, Sound, Light* (Seven volumes), Washington, National Science Teachers Association (n.d.).

Elder, Albert L., Demonstrations and Experiments in General Chemistry, Harper & Bros., New York, 1937.

Freeman, Maud, *Invitation to Experiment,* Dutton, New York, 1940.

Morholt, E. P., Brandwein, F., and Joseph A., *Teaching High School Science: A Source Book for the Biological Sciences,* Harcourt, Brace, New York, 1958.

in the cell are projected on a beaded screen. Opaque objects within the liquids appear in silhouette. Unfortunately all images are inverted —a fact that pupils should be made aware of before the demonstration is started.

The opaque projector has some important uses, providing the room can be darkened sufficiently. The greatly enlarged images enable all pupils to study rather small objects. Certain manipulations may also be viewed.

Mr Hurt wanted to show the action of sodium on water without using large quantities of the metal. He placed a pan of water in an opaque projector and sprinkled bits of sodium in it. The intense activity of the sodium was immediately apparent and the flames of burning hydrogen were distinguishable.

How many poor demonstration techniques can you find in this picture? What improvements could you make?

Dramatic effects can be achieved through the use of shadow projection. A strong light source with a condensing lens, such as a slide projector, is placed low in front of the apparatus. Shadows of the apparatus are cast on a white screen behind the demonstration table. By using a diverging beam of light from the projector the shadows are much larger than the objects which cast them.

LEAVING CLASSROOM WALLS

chapter 7

The classroom is a limited place, bounded narrowly by four walls and meagerly equipped for the task of providing pupils with worthwhile experiences. The world outside the classroom knows no bounds; it has almost every conceivable situation that a teacher might wish to utilize. In the school corridor pupils may study fire control measures or the effectiveness of a megaphone, or may determine the horsepower they develop when they run up a flight of stairs. Still within the building they can gain important experiences in the school shops, in the cafeteria, in the heating plant, and in the nurse's office. On the school grounds there are almost always plants, insects, birds, soil, paved surfaces, playground equipment, sunshine and shadows, flagpoles, building materials, bicycles, and automobiles. And just beyond the bounds of the school property lie the limitless resources of the community.

Many field experiences need only a few minutes for completion and nearly all can be accomplished within the limits of a period. Time need not be a limiting factor. Nor does transportation need to be a problem. A full program can be built up about the experiences within a few minutes walk of a school.

Miss Busch teaches biology in a high school in the heart of Brooklyn. She finds ample material for a field study program and has no sympathy for urban teachers who argue that field work is possible only in suburban and rural areas. "The challenge is naturally greater in the city," she says, "but that means that an urban teacher can do much more for her pupils."

Obourn, Ellsworth S., "Making the Most of Experimental Exercises," *The Science Teacher*, November, 1950, pages 170-171.
Miller, David F. and Blaydes, Glenn W., *Methods and Materials for Teaching Biological Sciences*, McGraw-Hill, New York, 1938.
Richardson, John S. and Cahoon, G. P., *Methods and Materials for Teaching General and Physical Science*, McGraw-Hill, New York, 1951, Chapters 1, 2 and 3.
Stollberg, Robert, "Science Demonstrations for Improved Learning," *The Science Teacher*, November, 1955, pages 277-279; 289-290.
Sutton, R., *Demonstration Experiments in Physics*, McGraw-Hill, New York, 1938.

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Sutton, R., *Demonstration Experiments in Physics*, McGraw-Hill, New York, 1938.

seclusion. Whatever observations are made of living things indoors should be considered as supplementary, not basic, experiences.

Field work permits firsthand study of many things that cannot be brought into the classroom because of size or inconvenience. It is only in the field that pupils can study real apple trees and power shovels and waterfalls. It is only on field trips that they can see song birds. It is only outside the classroom that they can investigate the operation of complete automobiles.

Field work permits a class to engage in activities that are too noisy or too violent to be used in the classroom. A soda-acid fire extinguisher must be operated outdoors. Model airplane gasoline engines demonstrated in a school building would disturb classes on every side.

Outdoors, pupils are able to work with large scale materials. A teeter-totter makes a more impressive lever than a meter stick, and erosion is better demonstrated with a stream of water from a garden hose than with a tiny trickle from a faucet.

Field experiences and the senses. During field work, all senses are brought into action. Thus pupils gain a more complete picture than from any other known method of teaching.

Genevieve is watching a huge derrick lift a steel girder into position for a new building. She has fixed her attention upon the graceful sweep of the great load through the air, but though she is not truly conscious of them, her senses are aware of much more. Out of the corners of her eyes she sees the erratic movements of men and machines—urgent gesticulations and ponderous obediences. Her ears are filled with the stuttering growl of hoisting machinery, the roar of truck engines, the clang of dropped steel, the shouts of workers. In her nostrils are the scents of raw earth, new concrete, sun-heated boards, tarred cables, motor oil, and the prevailing stench of engine exhaust. Beneath her feet the ground quivers as trucks roll by. All these sensations pile one upon another with almost frightening intensity and blend into the final picture Genevieve has of a large building under construction.

What comparable experiences could a teacher provide within the limits of the classroom? A model may give Genevieve an understanding of the mechanics of a derrick but it can give no impression of the magnificent power. A film may show the relative sizes of men and machines but fail to give the picture of everything working together. A recording can produce noises that approximate reality in pitch and rhythm but not in intensity or direction. Odors, so much more important than most people realize, cannot be duplicated. And the interaction of all the senses, the blending of sensations into the final impression, is pitifully incomplete.

Her trips take the pupils "no farther than one's feet can take him." She believes that arguments about transportation difficulties are apologies, not reasons, for failing to take advantage of the resources around the school.

For administrative reasons she takes her trips on Tuesdays. "As a result," she says, "our biology periods on Mondays are very exciting planning periods." The pupils must not only plan what they are going to do but also what they are going to wear because they have agreed not to let the weather interfere with their activities.

Her pupils have studied the way dandelions crowd out the grass in the school lawn, the secondary sex characteristic of city birds, and protozoa in puddles. "It is one thing to establish a culture in a battery jar in the classroom," says Miss Busch, "and quite another to look for protozoa in places which are part of our everyday environment."

In winter her pupils have studied temperature distribution in snow and have looked for insects. They have examined plants that stay alive and plants that die completely and have observed ways that plants make provision for new plants the next spring.

"Note that none of these trips are meant to extend beyond a regular period," Miss Busch points out. "We simply adapted our program to our allotted time. We worked in an outdoor laboratory." [1]

FIELD EXPERIENCES

Field experiences are firsthand experiences. They arise from direct learning situations. They play the same role in the learning of science as do experiments and demonstrations.

Special contributions of field experiences. Field experiences are generally much more closely related to the out-of-school experiences of young people than are the experiences gained in the classroom. Field experiences tend to be much more meaningful and permit easier transfer of learnings to the solution of real-life problems. Field work awakens many interests that classroom work cannot arouse. Field work is the study of actual objects, and objects stimulate more curiosity than do ideas. Out of almost any situation encountered in the field can develop a host of challenging problems.

The best place to study the reactions of plants and animals is in the field. Most living things do not react normally when brought into the classroom. Native plants are adversely affected by unnatural light and humidity conditions. Animals do not have proper diet, exercise and

[1] Busch, Phyllis B., "I am Prejudiced," *The American Biology Teacher*, January, 1957.

Many other sound experiments are best carried on outdoors. Studies of echoes can be made if there is a clear area of one hundred yards or more at the base of a large building. Megaphones are most effective outdoors. Doppler effects can be demonstrated by a boy blowing a whistle as he rides past on a bicycle or in a car. The Doppler effect is also noticeable when pupils bow over and straighten up as they listen to a passing airplane.

Much of the study of mechanics is more effective outdoors where large scale equipment can be used. Page 47 describes an experiment with a bosun's chair in which a pulley is suspended from a playground swing framework. Other pulley problems may be studied the same way. The outdoor laboratory makes possible the use of large levers, wheelbarrows, bicycles, and large inclined planes.

Laws of motion can be best investigated where there is space for things to move. Falling bodies may be studied by dropping different kinds of objects from fire escapes or high windows. Stopping distances of runners, bicycles, and even of automobiles—if a driver-education car is properly equipped—can be determined on playgrounds and streets. Principles governing projectiles may be discovered. The effect of trajectory angles can be shown with a stream of water from a garden hose and with a bow and arrow. Horizontal and vertical motion can be related.

The boys in Mr. Jordan's physics class wanted to measure the speed with which a pitcher could throw a ball. Mr. Jordan took the class outdoors and lined most of them up about ten feet from the base of the building. One boy was selected as the pitcher and directed to throw the ball between the row of observers and the building, trying to start the ball on as nearly a horizontal path as he could. The observers checked to be sure that the ball did not rise above the horizontal, using the rows of bricks as reference lines. Two pupils noted the height of the ball as it left the pitcher's hand. Another pupil noted where the ball landed.

The pupils then measured the vertical drop of the ball and the horizontal distance it covered. From this data they calculated the time the ball was in the air and with this figure they calculated the horizontal speed of the ball.

Many earth science activities should be carried on in the outdoor laboratory. Contour maps are much more meaningful when taken to a hill top or other observation point and related to the actual features of the landscape. Most weather measurements must be done outdoors. Erosion experiments need large scale equipment to approach accuracy.

At the Audubon Nature Center in Greenwich, Connecticut, experiments with soil erosion are carried on with two large wooden troughs about six feet long,

Learning—true learning—is the result of many sensations interacting and merging with one another. If one or more sensations is omitted during the learning process, the final impression is weakened, not only by the absence of the missing sensations, but also by the absence of their effect on each other.

Using field experiences to set problems. One of the most important ways to establish problems in science classes is to bring pupils into contact with things. Field work, of course, emphasizes the observation and manipulation of things. From the contacts thus made questions inevitably arise. Attempts to find answers to the questions give rise to new problems and thus horizons continue to expand.

Mr. Schmidt took his earth science class to a gravel pit in a glacial morraine. He directed the pupils to shut their eyes and pick up the first ten stones the hands of each encountered. The first question was, of course, "What kinds?"

The pupils classified the specimens by type and identified as many as possible. Mr. Schmidt helped with the unknowns. The pupils were then asked to total the numbers of each type and calculate the percentages represented.

New questions immediately arose. "Why should there be so many different kinds of rocks in one place?" "Why should 72% of the specimens be shale?"

Back in the classroom Mr. Schmidt directed the pupils in a study of glacial movements and the distribution of bed rock in the region. Pupils made maps of the possible origin of their specimens and the probable flow of ice that brought them to the gravel pit.

Outdoor laboratories. Teachers may consider the world around their classrooms as their laboratories, where they can carry out experiments on a scale and of a type impossible within doors.

Mr. Wilson's physics class planned a demonstration of the speed of sound. Two pupils were to carry an automobile tire rim as far away as could be seen from school, a distance of about 350 yards. There one pupil was to hold the tire rim suspended by a cord while the other pupil hit the rim with a hammer to which a white cloth was attached.

On the day of the demonstration the boys carried the tire rim to the place planned. Two others measured the distance to the school where the remainder of the class waited. By watching the white cloth the observers could tell when the hammer struck the rim. The interval before the sound arrived represented the time needed for the sound to travel the distance between the two points. Some of the pupils tried to estimate the time with a stop watch.

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Miss Dale gave her eighth grade science pupils kitchen strainers, flat pans, and glass jars, and took them to a nearby stream. In a few minutes the pupils had collected a rich variety of aquatic life to take back to the classroom for study. Aquariums were first set up. Then the pupils began a series of observations and experiments with their specimens, followed by references to books for information on life histories.

Units based upon field experiences do not differ in organization from those based upon classroom experiences. There are the same opportunities for experimentation, for reading, for summary and organization, and for project work. The only real difference is in the source of the basic experiences upon which the unit is built.

Field trips as follow-up experiences. Field work may be used in science units to show applications of the information gained through previous study.

Mr. Swanson's physics class had studied transformers in the laboratory, experimenting with models, dissecting a bell-ringing transformer, and testing a small commercial transformer. Near the close of the unit, Mr. Swanson took the class to a transformer station that serviced the community. Here the pupils saw the three large step-down transformers hooked into a three-phase network. Their attention was directed to the variation in size of conductors and insulators in the primary and secondary circuits.

The pupils also noted the cooling systems of the transformers, the lightning arrestors, the circuit breakers, and the voltage regulators. Upon their return to the classroom they read about these devices and discussed their operation.

Mr. Swanson's use of field experiences made excellent follow-up for laboratory experiences. The pupils had gained a knowledge of the construction and operation of miniature transformers from their laboratory work. The field trip showed them large transformers in actual use. The relative sizes of the insulators in primary and secondary circuits pointed out the "step-down" action of the transformers. The relative sizes of primary and secondary conductors emphasized the reciprocal relationship of voltages and current in a transformer circuit. The cooling system and the hum illustrated the energy losses in coils and cores.

In this instance, the field trip was more meaningful for being used as a follow-up activity than as an introduction to the study of transformers. Commercial installations tend to be complex and to contain accessory devices that confuse the beginner. A preliminary understanding of basic components makes it easier to trace events and processes in commercial installations.

two feet wide and six inches deep. These troughs are filled with soil and propped up on an incline. Measured quantities of water are sprinkled on the soil and run-off is collected from holes pierced through the lower ends of the troughs. One trough may contain bare soil while the other is heavily sodded, or there may be other combinations. Effects of different slopes can be shown by propping up one trough more than another.

Centering instruction about field experiences. It is possible to build many instructional units about materials that are available in the field. This places field experiences at the core of the learning activities.

Field trip possibilities exist in endless variety within a few minutes walk of every classroom door, beginning right in the school corridor itself.

Less than half a mile from the school where Mr. Dean teaches chemistry is the Portland Cement plant that is the chief industry of the community. Early each year Mr. Dean introduces a unit on the manufacture of cement and its properties. He takes his classes on trips to the quarries, to the plant, and to the testing laboratories. Nearly all laboratory and classroom work is an outgrowth of experiences gained in the field.

Within a short distance of most classrooms there are different but equally effective learning situations around which complete units may be centered. Sometimes a single trip can provide enough material for days of study.

from the school he must investigate the transportation facilities available.

Adapting the program for field work. Conventional planning procedures usually begin with the setting of subject matter objectives, followed by decisions as to the most suitable activities for attaining these objectives. There is a place for field experiences in a program so planned just as there is a place for experiments.

With conventional planning, however, many opportunities for field work are neglected because their contributions seem insignificant.

Miss Busch describes an urban field study thus: Many city children never saw a clover plant growing, although it is certainly very common. They are found on lots and borders. Have the pupils measure off a square foot and then count the number of plants. How many four-leaved clovers can they find? Compare the shapes and sizes of leaves. Dig up a plant to see the root nodules." [2]

If Miss Busch were teaching a conventional unit on reproduction, she might feel little enthusiasm for walking her pupils down three flights of stairs merely to see clover plants spreading by means of trailing stems. And for a conventional unit on interrelationships she might prefer to dig up a clover plant and take it into the class room to show the nodules.

Most units built around field trip experiences cut across conventional subject matter boundaries. A field study of clover plants involves reproduction, nutrition, symbiosis, inheritance, soils, and economic biology. The contribution to any one area is small. The total contribution is impressive.

A different planning sequence is recommended in order to emphasize field work. First, a survey of possible field experiences is made, then the learnings that may be gained from these experiences is determined, and finally plans are made with these learnings as objectives.

The resulting plans are necessarily unconventional, but they are adapted to the local situation and are profitable because of this. Experienced teachers have discovered that in the total program they cover almost the same material through plans based on field work as through conventional plans.

Mr. Moose planned an experiment to compare the effectiveness of a conventional program and a program based on field experiences. One class was exposed to the conventional method of teaching biology—classroom discussions and laboratory exercises. The other biology class was taken into the field throughout the school year. Insofar as weather permitted pupils

[2] *Ibid.*

Field trips for review and drill. Few teachers recognize all the potentialities of field work. Rarely does one see a teacher using field work for review and drill purposes.

Miss Birdsall took her eighth grade science class to see a sawmill as part of a unit on the growth and uses of trees. Two weeks later, in a review of the learnings of the trip and subsequent readings, Miss Birdsall brought the class back for a return visit. The pupils had an opportunity to review their understandings in a more impressive way than an oral review could have done.

Identification of things studied in the field can also be reviewed and tested in the field.

Mr. Martin gave his biology pupils duplicated sheets bearing numbers corresponding to numbers on tagged trees in a nearby park. At the park, he started the pupils, one at a time, on a circuit of the trees. As the pupils moved from tree to tree, they wrote down the names of the trees in the appropriate blanks on their sheets. Then Mr. Martin took the class around the same circuit so they could correct their answers.

Review work in the field can take the form of games and contests.

Mrs. Adams divided her biology class into two teams and announced a scavenger hunt. To the leader of each group Mrs. Adams gave a list of items to be collected. The list contained such items as the following:

1. *A piece of a plant that reproduces by means of spores.*
2. *An arthropod that is not an insect.*
3. *A perfect flower.*

The region in which the pupils must collect was defined and the time limit was established. The pupils were then dismissed to begin their hunt.

GETTING READY FOR FIELD WORK

A teacher encounters certain special problems in planning field work. For one thing, programs given in courses of study and in text books rarely emphasize field experiences as basic learning situations. A teacher must make certain adaptations in his program if he is to use field experiences effectively.

The teacher must also search for school and community resources for use in field work. Community resources have rarely been inventoried by a teacher's colleagues or predecessors.

Finally, the teacher must determine school policy about field work and fit his plans into any regulations established by the school administration. And if he plans to take his pupils beyond walking distance

went to parks and gardens and vacant lots where they could study such plants and animals as they encountered. All field trips were planned, of course, but if something interesting caught the eye of one of the pupils, Mr. Moose stopped to elaborate on it. The group exposed to conventional teaching methods was very conscious of the final state examination. The second group was not informed about the examination until the time came for review. Both groups reviewed for the examination for the same amount of time. Both groups performed about the same on the examination. Both attained approximately the same average grade.[3]

Surveying resources for field experiences. "Study indoors the things that are best studied indoors; study outdoors the things that are best studied outdoors." This is an excellent precept to govern all field work.

Within and around each school are hundreds of things worthy of study—resources far more valuable than are available in the most expensively equipped laboratories. Little things that are so common make the best things to study; one does not need a volcano, a blast furnace or a botanical garden for effective field work.

To make a survey of resources it is well to begin within the school building and on the school grounds because there are comparatively few problems when taking trips inside school boundaries. One may then explore the immediate neighborhood. Long trips are advisable only when the learning opportunities justify the additional time and effort needed. The list on page 161 may be of service in suggesting possible field study situations.

Administration of field trips. Trips taken within the confines of the school property present few administrative problems. Most school systems permit teachers to take their pupils anywhere within these limits without special permission. Sometimes, however, a principal wishes written notification of intent to leave the classroom.

Trips off the school property, however, involve the problem of liability for accidents. Policies governing such trips have usually been established by the school officials. Most principals justifiably insist upon a written notice which includes the names of the pupils and the destination of the trip. Some systems require written permission from each parent before pupils can be taken from the school grounds. This last requirement is a serious handicap in the case of short trips and teachers should try to obtain blanket permissions for trips within the immediate vicinity of the school.

Long trips, particularly those requiring the use of buses or auto-

[3] Personal communication from Dr. Carleton Moose, Professor of Biology, State University of New York Teachers College, Albany, New York, June 12, 1957.

hour, he was able to give his pupils almost an hour at the station by having them bring lunches to eat enroute.

Teachers must find time in their own busy schedules for field trips that take more than one period. Some schools provide these teachers with substitute teachers during the hours they are missing. Sometimes arrangements can be made with other teachers who have vacant periods. Sometimes pupils in unmet classes can be sent to the study halls with special assignments. Not infrequently in smaller schools the principal or vice-principal helps out.

Teachers may be concerned about supervision of the pupils during field trips. If the trips are to places where there are special hazards, it is desirable to have one or more adults along to help out. Sometimes a principal or a special teacher will consent to go along. Sometimes other teachers who are free go gladly. Parents may be asked to participate in such trips.

One teacher solved her problem in an entirely different way. She divided her class in two parts and took only one half at a time. The other half was sent to the study hall and to the library to work on special problems. By alternating the groups, she was able to have a much more manageable group in the field.

PLANNING AND CONDUCTING FIELD WORK

Four parents with cars were helping Miss Hunter take her seventh grade to study the plants and animals that live in and near water. The cars were driven to a small pond, and the pupils rushed off in several directions around the pond. Miss Hunter and the parents strolled along a path to the edge of the pond, chatting casually about the pupils and their activities. Within fifteen minutes the pupils began to move toward Miss Hunter. The first arrivals promptly displayed the specimens they had collected.

"Why don't you show that to Mrs. Bouton?" Miss Hunter told one girl. "That's an interesting find, Sylvia," she told another pupil. "Let's show it to the mothers who brought us out here."

Within twenty-five minutes all the pupils had returned and were getting into the cars for the trip back to the school.

"Miss Hunter," said one of the mothers, "How can you keep so calm? I used to be a teacher and I wouldn't have dared let the pupils go off in all directions by themselves. I would have insisted that they stay together."

Miss Hunter looked faintly surprised at the question and a bit puzzled too. "Why, I don't know," she said hesitatingly. "I guess I just expect them to behave properly and they do."

mobiles, are a different matter. Parents should know when their children are leaving the school for extended periods. Because long trips require considerable advance preparation, the request for parental permission imposes little hardship.

The majority of field trips should not require transportation. However, there may be some highly desirable experiences that could be given if some form of transportation were available. Schools that own their own buses commonly provide the buses for field work without question or limitation. Some allot a certain number of miles to each teacher, giving the individual teacher the option of using the mileage for a few long trips or several short trips. Other systems allot the use of buses on an hour basis. Small systems are generally more flexible than large ones.

Occasionally, a system budgets money for hiring buses for field work. Individual teachers must anticipate their needs for bus travel in making up their budgets for the following year.

When public carriers are available, as is the case in metropolitan areas, teachers may ask pupils to bring money for transportation unless school policy forbids this. The teacher must always anticipate the problem of those pupils who cannot afford the cost.

Parents may be willing to transport pupils in their personal automobiles. It is essential that these automobiles be properly insured.

Miss Donaldson, seventh grade teacher in a non-departmentalized school, used field trips extensively. She made requests for transportation through her "Mothers' Club," an organization that provided a number of services. There was rarely any problem in finding half a dozen mothers free to drive when field trips were planned.

Time for field work should rarely be a problem because so much can be accomplished within twenty or thirty minutes. Trips to distant places, however, may require travel time in excess of that provided by the schedule.

Some school principals look with favor upon field work and gladly excuse pupils from all classes for long trips. Other principals hesitate to excuse pupils arbitrarily but do not object if two teachers agree to exchange class time. Thus a science teacher and a mathematics teacher having successive periods with the same group may alternate classes on two different days, providing each with a double period.

If a science period precedes or follows the lunch period, it may be possible to extend a long trip through the lunch period by asking the pupils to bring their lunches.

Mr. Anderson wanted to take his earth science class to the local airport to see the weather station. Because his class met immediately after the lunch

has a megaphone, a public address system, or the voice of a bull. Discussions generally fail because pupils cannot hear each other and because there are so many distracting things to look at. Reading is difficult in bright sunlight. Writing is done under severe handicaps. And pupils are too exhilarated to sit passively as they might be able to do in the classroom.

But there are plenty of constructive things that can be done in the field. Pupils can be set at work on any number of problems. They can explore, collect, take measurements, experiment, or do anything else that demands physical effort.

When considering problems for field work it is generally wise to select those that permit pupils to work with their hands in some way. One should assume that if no provision for this type of activity is made, some of the pupils will probably find things to do with their hands, things that teachers would just as soon not have them do. During a five minute walk on the way to a park, pupils in a seventh grade class were observed to do the following things unrelated to the purpose of the trip:

1. Two girls walked along with their arms about each other.
2. Four girls picked up colored leaves.
3. Five boys picked up black walnuts and threw them.
4. Two boys tripped the girls ahead of them.
5. One girl chased the boy who tripped her.
6. One boy punched the boy ahead of him, was punched in return, and grappled with the boy momentarily.
7. Two boys continually jostled each other as they walked along side by side.
8. One boy broke twigs from bushes and a low branch and threw them at others.
9. One boy jumped up and pulled some leaves from a low hanging branch, then wadded up the leaves and threw them at pupils ahead of him.
10. One boy pretended to put a caterpillar down the necks of the girls ahead of him.
11. Three girls ducked and squealed at the pretended caterpillar. A fourth girl slapped the boy's face.
12. One boy snatched the "beanie" from another boy's head but was forced to return it by the teacher.

These are the normal reactions of preadolescents and early adolescents. The experienced teacher expects such behavior and is not upset by it. He does, however, try to provide substitute activities that are more constructive than those just listed.

Each year Mr. Walther took his chemistry classes to visit a junk pile. His pupils worked in pairs, each pair being provided with a strong magnet and

Miss Hunter greatly oversimplified her answer. It is true that she did expect the pupils to control themselves but that was because she had given the pupils a great deal of practice in self-control and she knew what she could expect of them. In addition, the trip had been very carefully planned to keep each pupil so busy he had little opportunity to do things that would have been undesirable.

Preparations had been made well in advance. The pupils were interested in finding out what kinds of plants and animals live around water. They had organized themselves into several groups, one group to look for submerged aquatic plants, another group to look for aquatic plants growing up into the air, a third group to look for aquatic birds, a fourth group to look for amphibians and reptiles, a fifth group to look for aquatic insects, and a sixth group to look for aquatic mammals or signs of their presence.

Within each group there was a division of responsibility. One pupil carried the special equipment, such as dip nets or field glasses. Another pupil carried containers for specimens that might be collected, while a third carried a field guide. One pupil took notes and another drew sketches for the frieze on aquatic life that had been planned.

Before making the trip the pupils had examined a map and decided where to go and the limits within which to stay. They had worked out procedures to be followed on the trip. They had written notes asking mothers to drive and they had assigned themselves to the several cars.

The pupils knew how to prepare for a trip in this fashion because they had taken many shorter and less elaborate trips. They were fully accustomed to taking responsibilities for their own activities during field work. They, too, "just expected to behave themselves."

Teaching in the field is no more difficult than any other kind of teaching. Miss Hunter had mastered the techniques and used them so naturally that she could not understand why anyone was surprised at what she did.

Applying psychology to the planning of field work. The boys and girls that a teacher takes on field trips are the same boys and girls that a teacher has in the classroom. Only the surroundings are different. It is the impact of these new surroundings that causes them to react differently.

Gone are the four walls and the patterns of behavior that were established during six or more years within them. Gone are the reflecting surfaces that throw back their own noises and make them conscious of their actions. Gone are the reverberations that give strength and authority to the voice of the teacher.

Lectures in the field are a practical impossibility unless the teacher

a file. The purpose of the trip was to study corrosion of metals. The magnets enabled the pupils to find pieces of iron, both rusted and unrusted. The files enabled them to investigate the metals hidden by corrosion and protective coatings.

The pupils collected samples of the metals to study in the classroom. During follow-up work they read about the nature of rust, performed experiments on the conditions causing rust, and investigated the types of coatings found on other metals. They also read about methods for coating steel with various other metals, paints, and enamels. Some carried out experiments with the processes involved.

Teachers should remember that the attention span of young people is no greater in the field than in the classroom and that there are many more distracting influences. Pupils should not be held to one type of activity for long intervals. There should be considerable variety in types of activities carried out.

Field study problems may be assigned to groups providing each pupil in a group can be given worthwhile things to do. In a group studying soil temperature, for example, the leader may locate and dig holes for the thermometer, a second pupil may take the temperature readings, a third may record the data. Meanwhile, other groups may work simultaneously on the same problem, or may undertake variations of it.

Miss Gibson's biology pupils were determining soil temperatures in a number of different places—in bare, packed soil, in luxuriant clover-bluegrass associations, in a poorly fertilized lawn, under a tree, and on the north side of a building. They worked in pairs, one digging a hole for the ther-

Before taking her biology class to visit a local bakery Miss Brown gave her pupils an understanding of the way bread can be prepared in the home. For laboratory work the pupils prepared dough with and without baking powder so they could see the leavening effect of the gas produced. By putting the dough in glass jars they could see the bubbles being formed in the dough.

Several girls volunteered to bake biscuits at home, using dough with and without baking powder so that the final effect of leavening could be studied. Two pupils prepared a demonstration that showed the evolution of carbon dioxide from yeast in a sugar solution. Miss Brown prepared a yeast dough which she let rise for a few hours before class in order that the pupils could see the effect of the yeast. Then she kneaded the bread and explained why this was done. All pupils had an opportunity to view a yeast suspension under a microscope.

These experiences enabled the pupils to prepare a list of questions on the problems of large scale bread making. The questions were duplicated and were used to guide their observations at the bakery.

It is often helpful to prepare work sheets for the pupils to fill in while visiting an industrial plant. In addition to guiding observations, they give the pupils something to do with their hands. Work sheets may contain sentences with blanks to be filled in, questions to be answered, tables to fill in, or spaces for sketches, diagrams or maps. These sheets may be prepared by the teacher or by the pupils themselves. More time for preparation must be allotted in the latter case but the time is generally well spent.

Below are the questions from a work sheet used by an eighth grade science class when visiting the pumping plant of the city water supply. The sheet was prepared by the teacher.

1. What is the source of Cortland's water supply?
2. What type of pumps are used?
3. What kinds of motors operate the pumps?
4. Why isn't the water filtered?
5. Why is chlorine added to the water?
6. How does the chlorine look as it is added?
7. How is the chlorine brought to Cortland?
8. How is the proper amount of chlorine measured?
9. How does the operator know how much water is being used?
10. How much water does Cortland use every day?
11. At what times of day is the most water used?
12. How much water might be used for putting out a large fire?
13. How much water do the storage tanks on Prospect Terrace hold?
14. What would happen if the main pump should break down?
15. What would happen if the electrical supply to the pumping station were cut off?

163. Each of her groups acted independently of the others because each had its own problem. Within the group there were individuals with particular responsibilities. In group work of this type there may be a chairman from each group who makes liaison with the teacher and who directs the others in his group. There may be secretaries, artists, collectors, and librarians.

The pupils in a class may not be ready for highly organized field work that involves much individual responsibility. They need practice with short trips and limited responsibilities first.

Trips to collect specimens are generally easy to conduct. Pupils need to know specifically what they are to collect, any special techniques needed for collection, the limits of the area in which they are to work, and the time limits that are set.

Mrs. Bayles arranged a fossil hunting trip to a nearby quarry for her earth science class. The pupils were divided in pairs but each person had a cloth bag for his own specimens. One hammer was provided for each two pairs of pupils.

Mrs. Bayles listed on the blackboard the names of the major groups of fossils commonly found in the quarry. She also showed some of her own specimens collected in previous years. She gave the pupils references to the fossils in their textbooks so they could look up their specimens themselves.

At the quarry the pupils immediately scattered and began searching through the loose rocks. Mrs. Bayles began hunting too but was soon forced to give her time to pupils who discovered specimens that puzzled them or that seemed especially interesting. Within twenty-five minutes most of the pupils were satisfied with their collections and willingly returned to school. A few, however, planned to return after school and continue their search for unusual specimens.

Visits to industries and other large scale operations are apt to involve serious problems. Rarely are the pupils permitted to operate devices or manipulate materials or make collections. Commonly, they must go single file past machines, and thus become separated from the leader by a distance that makes control difficult. Pupils are often at such a distance from the leader that they cannot hear him tell about machines or processes. Sometimes there is so much noise that only a few of the closest pupils can grasp the leader's words. When the leader is not accustomed to working with young people, he may use technical language that handicaps them in understanding what he is talking about.

Careful preparations help make such visitations more effective.

have planned to take certain notes or make certain sketches for use in class at a later time.

Mr. Smalley's ninth grade science class planned to construct miniature dioramas showing the habitats of animals in which they were interested. To get ideas for their projects and to check on the accuracy of the work already started, the class visited the city museum to view some of the superior dioramas of the major habitats of the state—plains, foothills, high mountains, deserts, and irrigated fields. The pupils made notes and sketches to help them after they returned to the classroom.

The teacher's role during field work. The account of Miss Hunter's field trip as given at the beginning of this section illustrates the proper role of a teacher during field work. Miss Hunter served as a consultant for the pupils as they brought in their materials. She did no lecturing. She did not interrupt the work of the pupils with loud voiced comments or last-minute directions.

If a teacher can be free of instructional responsibilities during field work he may watch his pupils more closely and give specific help and encouragement when needed. He is able to provide proper recognition for pupil achievements. And he can sense general progress, so that he will be prepared to bring the field work to a close at the optimum time.

Personal enthusiasm for field work is a great asset to a teacher. If he can greet unusual finds or accomplishments with expressions of strong interest, pupils are stimulated to continue their efforts. Often a teacher needs to work along with the pupils, displaying by his own example how interesting the work is.

Generally a teacher should not interrupt the work of the pupils. Occasionally, however, something unusual arises and justifies an interruption.

A seventh grade class was making a study of the blooming habits of dandelions on a park lawn, measuring lengths of stems and marking specimens to be measured on succeeding days. As they worked, a flock of grackles in a spruce tree became very noisy.

"If those were crows I would say that they had discovered an owl in that tree," the teacher said to a couple of pupils near him.

"May we go look?" they begged.

"Why, I guess so," the teacher told them.

A moment later they shouted, "There's an owl up here. Come quick!"

The teacher motioned them to be quiet and, calling the pupils together, led them as inconspicuously as possible to the tree. There on a limb sat a barn owl, less concerned about the pupils than with the grackles who pestered him until he flew away.

16. What would happen if the water supply began to dry up?
17. What would happen in case of a large fire?
18. How long would Cortland have water if the pumping station were destroyed?

"Flow diagrams" are helpful in keeping in mind the sequence of operations in a complex industry. Pupils need advance instruction in the meaning of the symbols. Figure 9 shows a flow diagram prepared by the teacher of a chemistry class for its visit to a wire products manufacturing plant.

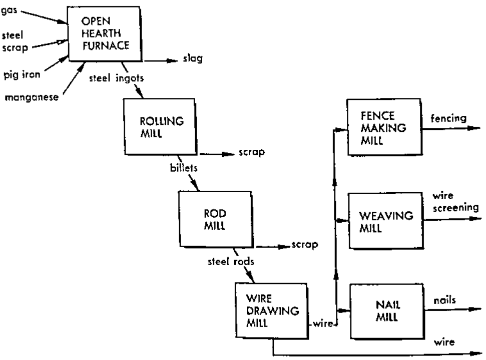

FIGURE 9. *Flow diagram of wire products factory.*

Museum visitation may require less advance preparation than a trip to industrial plants. Museums are set up as educational institutions with the nature of pupils in mind. Most modern museums provide opportunities for boys and girls to manipulate things, to operate devices, and to observe things that move or change in some way. Special attention is given to the language on labels and to the types of problems set up. Many museums also provide specially trained guides for school groups.

Nonetheless, certain preparations make museum visits more meaningful. Pupils should certainly have a well defined objective for their visit, preferably a problem that they want to solve. They may also

Sometimes problems raised during one field trip are best answered by a second trip.

After a ninth grade science class had visited an ice cream plant, the pupils raised a great number of questions. "Was the method used for pasteurizing the milk the same as was used for their bottled milk?" "How was the butterfat content measured?" "How was the cream used removed from the milk?" "What is homogenized milk?" The teacher believed these questions could best be answered by arranging for another trip, this time to a milk processing plant where bottled milk was produced for table use.

BROADENING THE OPPORTUNITIES FOR FIELD EXPERIENCES

Although there may be numerous possibilities for field work within a short distance of the school, there may not be enough time to take advantage of them, or there may be some of special value to certain pupils but not to others. Some may exist beyond practical travel range for a class. And occasionally a teacher wishes that certain possibilities existed where they do not. Solutions have been found to all these problems.

Optional field trips. Enthusiastic teachers may arrange optional trips for their science pupils.

On the average of once a month, Mr. Kendall invited his general science pupils to go with him on Saturday morning hikes. There was no special objective for the hikes. They might lead to a pond, a stream, a woodland, a field, or a swamp, just to "see what was going on." Only a small number of pupils took advantage of the opportunity, perhaps a dozen or so each time, depending upon the weather, but their enthusiasm was high and stimulating to other pupils.

Night trips appeal strongly to young people, possibly because of the excitement of going out after dark and partly because young people like to get away from home into the company of their peers.

Each spring Miss Barber took her seventh grade science pupils on a "peeper hunt" to catch some of the tiny tree frogs that enliven temporary pools of the northeastern states during the months of March and April. The pupils were asked to come dressed in warm clothing and boots, and to bring a flashlight and a glass jar. Parents provided the transportation to the puddles where the pupils were to begin the hunt. A few peepers would be carried back to the classroom for study.

Astronomy "hikes" are popular. The pupils are asked to meet at a central location from which they walk to an open place where street

The pupils returned to their work, possibly less enthusiastic about dandelions but enriched by the experience.

There are occasions when it is justifiable to change the purpose of a trip. Not infrequently, some temporary condition arises, something that can be utilized at the moment but which cannot be seen again.

Mr. Dutter was taking his biology class to compare the vegetation in a woodland where cows were pastured with a woodland from which cows were excluded. He stopped at a farm to explain that he was going into the woodland, having requested permission previously. He learned that at that moment a cow was being inseminated artificially. He immediately asked if his pupils could watch and they stayed until the act was completed. Mr. Dutter felt that the experience was a valuable one and should be utilized. The woodlands, on the other hand, would wait until another day.

Follow-up activities for field work. The value of field experiences is greatly strengthened by providing suitable follow-up activities. Pupils need opportunities to sum up and organize their learnings. Oral and written discussions, so often used, have some value, but various types of project work leave more lasting impressions.

A general science class visited the municipal water supply system. After their return the pupils constructed a large working model of the system.

In addition to models, pupils may make charts, friezes, posters. They may prepare exhibits of materials collected. They may organize bulletin board displays of pertinent pictures. Sometimes they can dramatize conditions seen during the trip.

Most field observations give rise to numbers of problems. Some of these problems can be answered by follow-up experiments.

A trip to a swift stream showed seventh grade pupils a gorge dug in bed rock and, farther downstream, deposits of rounded pebbles. After returning to the classroom, the pupils experimented with the erosional forces of moving water. They put freshly broken fragments of soft rock in glass jars of water. They then shook their jars vigorously for a hundred times. The fragments now showed slightly rounded edges, the water in the jars was clouded with sediment, and the jars showed scratches on their inner surfaces.

Other problems may be solved by reference to books, magazine articles, or other authorities.

A chemistry class visited a bottling plant to see how water is carbonated for soda pop. The pupils wondered how the carbon dioxide in the pressure cylinders was obtained. As part of their assignment, the teacher asked them to read about the commercial production of carbon dioxide.

Mrs. Dale knew of a man who raised orchids as a hobby. She suggested that two pupils might visit the man and report back to the biology class on his activities. June and Sylvia volunteered.

The girls found the visit very interesting. The man was experimenting with raising his own plants from seeds. He not only told them about orchids in general but was able to demonstrate the problems of germinating the tiny seeds.

After the visit the girls made an excellent report to the class. They were able to illustrate their report with pictures from catalogs, with two blooms, and with some samples of seeds and seedlings that were given them.

Young people commonly engage in such activities as hiking and camping with scout groups, picnics with parents or clubs, and hunting and fishing. Teachers can make suggestions for things to do during these activities and thus enrich the science backgrounds of the boys and girls engaged.

Henry and Charlie were probably the most avid fishermen in the school. They went out at every available opportunity. Mr. Medhurst asked the boys to keep track of some great blue herons that were beginning to nest in a swamp where the boys often fished. The boys kept good records of the progress of the colony for several years.

Parents may help pupils with their field work, particularly in providing transportation to places beyond walking distance.

Mr. Dunlop discovered a newly opened road cut where an anticline and a fault were plainly visible. Along the fault plane were rock fragments bearing slickensides, veins of calcite, and crystals of both quartz and calcite. Mr. Dunlop told the pupils about his discovery and gave precise directions for reaching it. Over the weekend more than a quarter of his earth science class had persuaded their parents to taken them to the site.

Recognition for voluntary field work. Pupils need recognition for the field problems they undertake after school hours. One way to give such recognition is to provide opportunities for them to report on their activities.

Mr. Jenning set aside the beginning of his general science classes each Tuesday morning for "scout" reports. At this time pupils could tell about their observations during the preceding week, particularly those made over the weekend. Most of these reports dealt with observations of plants and animals.

lights do not interfere with star finding. The pupils are cautioned about dressing warmly. They may bring flashlights, "tin can planetariums," and other devices to help in finding the stars and constellations.

Parents often enjoy participating in optional field trips and will drive if transportation is needed.

Mr Davenport arranged a series of Saturday morning trips for his junior high school science pupils. Parents were invited and some of them provided the transportation. Trips were taken to a ledge rich with fossils, a museum showing the development of the local salt industry, a beaver dam, a fish hatchery, and a foundry. Parents said they enjoyed the trips as much as their children.

Voluntary field work. Pupils voluntarily undertake field problems that specially interest them, spending long hours in field work outside of school hours. Sometimes these problems are suggested by teachers as optional assignments; sometimes the problems grow out of work done in class.

Miss Jones took her eighth grade science classes on field trips to an open field where they collected wild flowers. Returning to the classroom she showed the pupils how to press and mount the specimens. Within a few days a large number of her pupils had taken independent trips to gather additional specimens for their collections.

A teacher may ask pupils to investigate devices within their own homes. This is a form of field work.

Mr. Frier's science classes were studying home heating systems. He asked each pupil to investigate the heating system in his own home, making diagrams and writing up a report for his notebook.

Pupils can also be asked to make visits to places where they may study material being taken up in class. Care should be taken not to send them to places where there is danger.

Mr. Tremont wanted his ninth grade science class to see an automobile motor block so they would know what cylinders, pistons and valves are like, but he had no motor block available in the school. However, a large general merchandizing store had motor blocks for sale. Mr. Tremont asked each pupil in his class to visit the store and look at the displays.

Pupils generally like to work together on out-of-school projects. If teachers suggest a number of practical problems, pupils often undertake them eagerly.

trips and out of their own special interests, the members become engaged in individual research projects which they write up and present at the club meetings or to scientific organizations if possible.[4]

School gardens. School gardening has been an established part of the elementary school program in a number of cities since early in the century. In some instances special supervisors are employed to give continuity to the program through the summer months.

The school garden is an equally good laboratory for the secondary school sciences. Many important problems that do not lend themselves to indoor study can be investigated in a garden. The garden also instigates problems that can be worked on through the winter months and projects that individual pupils may carry out through the summer vacation.

Any part of the school grounds may be utilized as a school garden if it does not interfere with other activities.

Mr. Tillman was a general science teacher in a new school that had just been landscaped. He asked for permission to use the space between the newly planted shrubbery for some special studies. During the fall his pupils planted several kinds of bulbs and watched their development the next spring. The pupils learned about the dormancy of bulbs, the reactions of flowers to temperature and sunlight, and the methods of pollination.

The major problem in school gardening is the care of the gardens during the summer months. Where there is a special supervisor, such care is assured. In other situations, a custodian may be given the responsibility for the plot. Privately owned gardens, from which sections are loaned for experimentation, receive the needed care by their owners.

Mr. Miller uses portions of privately owned gardens for his laboratories. Problems that pupils have worked on include: (1) how to replace Kentucky bluegrass with Winter Rye; (2) how to irrigate a small garden properly; (3) how to start a compost pile; (4) how organic matter changes into humus; (5) what the life cycle of the common cabbage butterfly is; (6) what effects various gardening techniques have on the growth of mustard plants.[5]

Wildlife laboratories. One penalty paid for suburbanization is the loss of natural areas where boys and girls can become acquainted with native plants and animals. All the movies, television programs, expensive laboratories, city parks, and supervised playgrounds cannot

[4] This club is described more fully in chapter 22.
[5] Miller, M. C., "The Garden Laboratory," *The American Biology Teacher*, November, 1955.

It is helpful to provide a table on which pupils can display things associated with their field work—specimens collected, experiments, and models. These need have no relation to the regular classwork.

A science column in the school newspaper gives pupils opportunities to report on their field work, and thus to gain recognition from other pupils outside their science classes. One teacher sponsored a weekly mimeographed bulletin titled "Nature Notes" to publicize the field work of her junior high school science classes. One science club gave a fifteen-minute radio program on field observations each week.

Sponsors for field activities. Many people with no direct connections to secondary schools can provide rich field experiences for young people. Some of these laymen work in scouting and are trained in helping adolescents. Most laymen, however, lack such training and have only their own enthusiasm to depend upon. They work best with boys and girls who also have strong interests.

In many communities there are bird study groups that meet regularly for early morning bird hikes and for exchange of field notes. The leaders of these groups are happy to add interested young people to their numbers.

Camera clubs often enroll young people. Of course it is necessary that these young people be financially able to bear the expenses involved in photography. Amateur astronomers commonly put themselves and their equipment at the service of teachers. When they find interested young people they often extend invitations for continued work and they sometimes help these young people build their own telescopes.

Local industries are opening their doors more and more often on "Let's Get Acquainted" days. Sometimes the general public is invited, sometimes only the families of workers are invited. Science teachers should encourage pupils to take advantage of these opportunities.

Science clubs and field experiences. Science clubs commonly include field trips in their programs.

Mr. Decker's science club plans four or five major trips a year. Some of the trips are taken during the regular meeting time and run over into the hours after school. Some are taken on Saturday. The administration allows the club to take one full day a year from classes and provides a bus for transportation.

A science club may devote its entire program to field work.

The Wyandotte High School Field Club sponsors seven yearly field trips, some one day in length and some lasting through the weekend. Out of these

teacher, has been responsible for the project from the beginning. Trees have been planted, erosion control measures have been adopted, and a pond has been constructed. Mr. Anderson has a science club that has been responsible for many of the improvements.

The learnings that are possible in a field situation cannot be duplicated in the classroom. They cut across traditional boundaries and have an impact far greater than the learnings gained from books and films. These pupils are studying woodlot management on a farm acquired by a school system as a conservation and biology laboratory.

City parks are often large enough to contain a few acres of natural area, but park authorities usually think in terms of neatly clipped lawns and ornamental plants. Sometimes, however, they can be convinced that natural areas are needed.

An estate was willed to the city of Brookline, Massachusetts, to be used as a park. About five acres of this tract, containing two ponds, was excellently suited for an outdoor laboratory. Mr. Keene, of the Brookline High School, and chairman of the "Natural Areas for School Grounds in Massachusetts" sponsored by Nature Conservancy, tried to get the park authorities to set aside the plot for school use.

"Working alone for the establishment of the Conservation Center did not prove very successful," he says. "This was something new for this region. I was pioneering and the road was rough at first. I enlisted the aid of our Garden Clubs. These ladies saw the value of natural areas for our boys and girls. Finally, after much hard work on the part of many, the Park Board

compensate for the loss. Science teachers, if for no more than selfish reasons, should be among those most vigorously active in trying to preserve or to restore natural areas near their schools.

Sometimes a school district already owns the land that can be used if teachers will press actively for it.

The West Lafayette, Indiana, Schools owned about three acres of undeveloped land in a residential area. The land had become littered with trash and was an eyesore to the community. Undoubtedly pressures would have been exerted upon the school board to clean it up and convert it into lawn or playground. But Mr. Bush, the biology teacher, and Mr. Floyd, the superintendent, could see reasons for developing the area as a natural outdoor science laboratory.

Mr. Bush initiated a number of class projects designed to make the area useful. First the pupils cleaned up the trash. Then they planted native trees and shrubs and started wild flower gardens. They put up signs identifying interesting features. They built bird houses, bird feeders, and provided suitable types of cover for concealment. They began a number of soil conservation practices.[6]

When school systems acquire land for buildings and grounds, some parts are often excellently suited for nature areas if they can be preserved before bulldozers begin to operate. Again, science teachers must be alert to the possibilities.

Miss Larsen persuaded the trustees of the Carmel, California, High School to set aside two and a half acres of land for science work. Among the problems undertaken in this outdoor laboratory have been: (1) the nature of soils and the effect of weather on them; (2) rates of plant growth; (3) kinds of plants and animals living on the tract; (4) location of examples of interdependence; (5) the prevention of gulley erosion.

From the first there has been much individual project work on the plot. Bill chose to study the rate of growth of Monterey Pine seedlings. Francis made a study of the nesting habits of the wood rat. Melinda began a plant collection for the use of future classes. Susan prepared soil profile charts. Tam and Melinda studied the habits of some of the birds.[7]

Sometimes the school district is willing to acquire land solely for the purpose of outdoor laboratories.

The Norwich, N. Y., school board purchased an abandoned farm as a science and conservation laboratory. Mr. Anderson, general science and biology

[6] Floyd, William and Bush, Kenneth, "School Homesteading—Viewpoint of the Biology Teacher," *The American Biology Teacher*, May, 1956.

[7] Larsen, E. A., "Opportunities for Exploration and Discovery," *The American Biology Teacher*, December, 1955.

PROGRAM OF THE ST. CLAIR HIGH SCHOOL SCIENCE CAMP

4:45 AM	The group leaders were awakened.
5:00	Groups having bird observations were aroused.
6:00	The other half of the camp was awakened for detail and breakfast preparation. These groups alternated their activities each morning.
7:00	The bird observation groups returned and breakfast was served.
7:30	General clean-up for the duty half of the camp. (Bird observation groups had this time free for personal care.)
8:00	The groups mustered at the bus loading area to begin the day's activities.

The soils group, upon arriving at their area, experienced problems in soil management, erosion, bank control, etc. The forestry unit was concerned with types and uses of trees, growing and planting of them, in an actual work situation. The wildlife group combined both the practices of game management and the proper method of handling firearms and conduct in search of game. The nature study group, using the general camp area, was able to study the topography from lake shoreline to open fields. They were able to make comparisons of plants and animals within these areas. This group, because of the lack of transportation time, was able to return to camp and set up for the next meal preparation.

12:00 N	Lunch
12:30 PM	Work details
1:00	Back to work areas
5:00	Supper
5:30	Half the groups were on bird observations and the others were on camp details.
6:00	The work details mustered for a lecture on camping, particularly survival camping.
6:30	All returned to the area for recreation, such as volley ball, swimming, capture the flag, etc. Parents helped supervise.
8:00	All gathered on the beach for a bonfire, songs and a general good time.
9:00	Back to the tents. Group leaders met.
9:30	Lights out.

granted the use of this five-acre plot as a Plant and Wildlife Conservation center." [8]

School camping. One interesting development in modern education is school camping. It is a movement in which science teachers can find the answers to many problems. In camping programs, boys and girls encounter at first hand situations they merely talk about in school and rarely encounter in everyday life. The problems of fire building and elementary sanitation and nutrition become real rather than academic problems. Young people develop the backgrounds of experience so necessary for much of what they read about and study in secondary school science.

School camping programs range from day camps to two-week experiences far from home. Sometimes trips are taken on weekends and holidays only, sometimes the program is given during the summer vacation; occasionally camping becomes part of the regular curriculum.

More and more schools are buying property specifically for their camps. Others are renting or leasing land. Many schools make use of public lands in state and national parks.

Few school camping programs are set up specifically to teach science, nor do they need to be. Experiences gained in camp are largely basic science experiences no matter how the program is designed. There is the chemistry of fire-building, the mechanics of rowing a boat, the natural history of the organisms encountered, the geology of stream and wave action.

However, many opportunities for science experiences are neglected in school camps that are operated solely by physical education and recreation staff members. Science teachers have not always shown the interest in school camping that they might. When they take the initiative some very fine programs have resulted.

Mr. Dawson of the St. Clair High School in Michigan sponsors a science camping program. He takes as many as 55 boys and girls to public lands where they live in tents, do much of their own work about camp, and engage in an intensive study of natural science.

The program of the camp is given on page 181. Speaking of the outcomes of the program, Mr. Dawson says, "Each individual had some unique experience and awakening that was strictly his own . . .Almost without reservation it can be said that each individual progressed in some way. In some it was greater, but even the student who just took part was making great strides." [9]

[8] Keene, I. C., "Establishing a Plant and Wildlife Area in a City," *The American Biology Teacher*, February, 1957.

[9] Dawson, J. R., "Learning from the Outdoors," *The American Biology Teacher*, April, 1957.

AUDIO-VISUAL AIDS IN SCIENCE TEACHING

chapter 8

There are times when firsthand experiences cannot be provided for pupils. An earth science class cannot be taken to Greenland to see an ice sheet. A biology student cannot sit patiently watching a bud while it opens. A physics student cannot see what goes on inside a vacuum tube. It is then that a teacher must use substitutes for reality—photographs, drawings, models, recordings.

Most of these substitutes make use of the pupils' vision; a few depend upon the sense of hearing. In consequence, the term "audio-visual aids" has been coined. The term is not a good one because these same senses are involved in all good learning situations and the term can be applied to all apparatus used in experiments and all materials studied in the field. However, in this chapter common usage will be accepted and "audio-visual aids" will refer only to those devices used to provide substitutes for firsthand experiences.

CHARACTERISTICS OF AUDIO-VISUAL AIDS

For convenience in discussion, audio-visual aids are generally grouped under four headings: (1) photographs and reproductions of photographs, (2) paintings and drawings, and reproductions of these, (3) models, and (4) recordings.

The contributions of audio-visual aids. Each of the four types of audio-visual aids makes its own contribution to the educational proc-

Suggested activities

1. Visit a typical secondary school and make a list of the field experiences that are possible in and near the school building.
2. Go with a science class on a field trip. Make notes on the actions of the pupils. Try to analyze the reasons for their behavior.
3. Take a group of pupils on a short field trip. During planning, make certain that each pupil has meaningful activities to keep him busy. If this cannot be done with a group of high school pupils, conduct the field trip with members of your methods class.
4. Make plans for an extended field study in which pupils work in groups of four or five. Make sure that each pupil in each group has meaningful activities to busy him at all times.
5. Go through a standard textbook in each of the major areas of science. Suggest one or more practical field experiences to enrich each chapter or unit of the textbook.

Suggested readings

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AUDIO-VISUAL AIDS IN SCIENCE TEACHING

chapter 8

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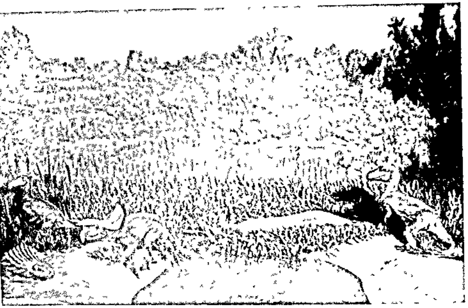


Through visual aids pupils can become acquainted with things of the past and things in far distant places. Dioramas are often used to present three-dimensional reconstructions of historical settings. This diorama was made with purchased models of dinosaurs. Pupils may make their own models from clay, papier mâché, or plaster.

ess. Sometimes, when two or more types can be brought to bear on the same topic, their strengths are pooled and their limitations are minimized. Following is a discussion of the situations in which audio-visual aids may be employed profitably.

1. *To present exotic material.* Chiefly through photography, but to a limited extent through paintings and dioramas, pupils can be given understandings about science materials in distant places. Some sound films and recordings also help enrich the experience background of pupils.

2. *To present historic material.* Since the introduction of photography there have become available a wealth of authentic photographic records of important events, places and people. Most of these are in the form of still photographs but there are increasing numbers of films.

To provide information about events and people prior to the invention of photography there are reproductions of contemporary paintings and drawings. There are also modern paintings and drawings that reconstruct conditions and events of the past. Museums sometimes contain reconstructions as dioramas.

The library of tape recordings and records of the sounds of historical events is growing. Some are available today and many more will be

available in the future. Teachers may make tape recordings of radio reports and thus build up their own libraries.

3. *To present information about inaccessible places.* It is often impossible to visit local industries and other prohibited places in the region. In such instances photographs and films are the only means possible for giving pupils information visually.

4. *To give a "bird's-eye" view.* Many machines, industries and topographic features are too large to be grasped from the usual viewpoint. Aerial photographs are useful in showing the relation of parts or features to each other. Scale models have the advantage of including a third dimension. Both scale models and working models show the relation of the component parts of large machines.

5. *To summarize a series of observations.* After a field trip to an industry, a suitable film presents a quick summary of things seen on the trip. Flow diagrams and bulletin board displays of relevant pictures serve the same purpose.

6. *To present information about microscopic materials.* There are many materials which pupils cannot prepare for examination through a microscope. Photographs and projected slides are useful for presenting information about these materials. Films can be used to show the behavior of microorganisms that are difficult to obtain. Large scale models are especially valuable to give pupils a concept of the third dimension that is lacking when viewing objects through high power microscopes.

7. *To amplify sounds.* Faint sounds such as heart beats can be picked up with a stethoscope and amplified with a radio amplifier so that an entire class may hear them. There are also recordings of amplified sounds available.

8. *To acquaint pupils with elusive organisms.* Few pupils have ever seen a mole or a shrew, common though these animals are. Photography makes it possible to acquaint pupils with these and other little-seen organisms. Recordings of the calls of frogs, insects and song birds help pupils associate commonly heard sounds with the rarely seen animals that make them.

9. *To present things usually seen by inadequate light.* Bats are often seen but are seen too indistinctly for the observer to comprehend their details. Flash photography has done much to acquaint people with nocturnal creatures.

10. *To acquaint pupils with infrequent phenomena.* Such phenomena as rainbows are rarely seen at the time a teacher wishes to deal with them in class. Photographs and paintings recall the past experiences of pupils and give opportunities for study of formerly unnoticed details.

11. *To acquaint pupils with dangerous conditions.* An explosion of gasoline fumes is not a suitable large scale demonstration for science classes, but a film of such an explosion can be used effectively.

12. *To acquaint pupils with materials that are difficult to keep.* Many desirable teaching materials cannot be kept in satisfactory condition long enough to justify their cost. Organs from the human body, for instance, are expensive to buy and difficult to keep. Colored photographs are often to be preferred to "pickled" specimens. Better yet are full-scale models.

13. *To help pupils make comparisons.* Two or more sequential photographs permit comparisons of changes that might otherwise go unnoticed. Still pictures permit more detailed comparisons than do films. Recordings permit comparisons of sounds that ordinarily might not be heard together.

14. *To speed up gradual changes.* "Time-lapse" moving pictures make such normally slow changes as the growth of a seedling seem to occur very rapidly. Thus changes not usually noticed become obvious.

15. *To slow down action.* The wing motion of a humming bird is too rapid for the eye to analyze. By the use of "slow motion" moving pictures it is possible to study the movements of the wing and even the behavior of individual feathers.

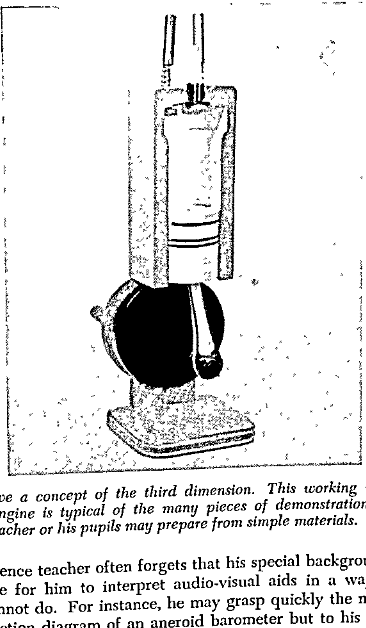
16. *To stop action.* The development of electronic flash has made it possible to take pictures with an exceedingly short exposure. These pictures can be used to analyze conditions that last for no more than a few thousandths of a second; for example, the distortion of a tennis ball when it strikes the floor.

17. *To show the action of devices not easily studied.* Working models are useful for showing how machines operate, indicating the basic parts, often simplified, and their action. When complex machines are studied, a series of models, each illustrating a portion of the total organization, helps to clarify understandings.

18. *To show the interior of things normally enclosed.* Cut-away drawings and phantom drawings are excellent for showing the relationship of interior structures. Sectional drawings are useful for those who know how to interpret them. A series of photographs or drawings made while an object is being constructed or taken apart may give desirable concepts. Animated drawings, either sectional or in phantom view, give the relationship of moving parts.

Cut-away models and dissectible models are often to be preferred to pictures because they give a concept of the third dimension. Phantom models having exterior coverings made of transparent plastic are expensive but are finding increasing use.

Limitations of audio-visual aids. The chief limitation of audio-visual aids is their lack of reality. Pupils are faced with the problem of interpreting—producing images representing actual conditions. A pupil who has seen an apple undoubtedly interprets correctly the photograph of an apple. But the pupil who has never seen stylolites might have considerable difficulty in realizing what a picture of these structures represents.



Models give a concept of the third dimension. This working model of a gasoline engine is typical of the many pieces of demonstration apparatus that the teacher or his pupils may prepare from simple materials.

The science teacher often forgets that his special background makes it possible for him to interpret audio-visual aids in a way that his pupils cannot do. For instance, he may grasp quickly the meaning of a cross-section diagram of an aneroid barometer but to his pupils the diagram may be no more than a set of lines.

Photographs and drawings have two dimensions, but they must be interpreted in three dimensions. When they represent familiar ob-

jects pupils have no trouble adding the third dimension. If they have never seen the object represented they may not be able to see more than two dimensions.

Diagrams are much more difficult to interpret. So much detail has been eliminated from a diagram that it ceases to resemble anything real, save as the mind is able to supply the missing portions. Cross-sectional diagrams are particularly difficult for many pupils to interpret.

All images produced from audio-visual aids are necessarily incomplete. Two senses alone are involved and these may give distorted impressions. Lacking is the fusion of all the impressions gained by all the senses.

Audio-visual aids tend to give distorted images. Pictures may give no clue as to size: pupils seeing equal sized photographs of a cat, a cow and an otter would probably recognize the relative sizes of the cat and the cow but might think of the otter as being as large as the cow if there were nothing in the picture with which to make comparisons.

Photographs are often distorted deliberately for "artistic" effects. The camera may be held at an unusual angle, or provided with special lenses, or altered to increase the foreshortening. The resulting photographs are likely to produce incorrect or confused images in the minds of many pupils.

Photographers distort the information provided by a photograph in order to emphasize a point. They blur out the background, provide artificial backgrounds, use unusual lighting. Sometimes they deliberately falsify; propaganda films commonly cut out all scenes giving contradictory evidence.

Models are commonly distorted. Topographic models generally have an eight-to-one distortion, making mountains seem higher and steeper than in reality. The distortion in astronomical models is generally so great that most people have totally wrong concepts of the size of the solar system and the distances between its components.

Models may give wrong impressions because of the materials of which they are made. A model of a human heart, made of rigid papier-mache or plaster, does not give at all the image of a mass of muscle—flexible, vibrant, pulsating.

Miniature working models may give wrong impressions because not all forces can be reduced accordingly. A miniature landscape being eroded by a miniature stream flowing across it does not illustrate large scale erosion with any precision. In a small model, the effects of adhesion, cohesion and surface tension play a considerable role in the movement of the water and the particles of soil. In large scale erosion, as is seen outdoors with rivers, these same forces are negligible.

Sounds can be distorted too. Recording equipment cannot record the full range of sounds audible to the human ear. Most play-back equipment found in public schools is even less faithful in reproduction. Lost are the high and low frequency vibrations. In addition, low quality amplifiers and speakers overemphasize some frequencies and underemphasize others. Intensities must be distorted because very loud sounds cannot be recorded or reproduced by most equipment. This results in sounds that are perhaps identifiable to the person who knows them but that may be confusing to others.

Devices needed for use with audio-visual aids. Although some of the audio-visual aids, such as photographs, may be put directly in the hands of pupils for study, many of them require special projection equipment. All science teachers should master the operation of each of the following devices as soon as possible; all are highly useful to him and some, such as film projectors and tape recorders, need trained hands lest serious damage result.

1. *Bulletin board.* This is used for displaying photographs, drawings, and other flat materials.
2. *Chalk board or blackboard.* The teacher uses this most commonly for line drawings.
3. *Charts.* These display large line drawings. They may be purchased or constructed by pupils and teachers.
4. *Opaque projector.* This machine makes it possible to project an image of photographs and drawings on a screen for class study.
5. *Duplicating machines.* Copies of line drawings can be produced in quantities by standard office duplicating machines.
6. *Photographic and photostat equipment.* This equipment produces copies of photographs and line drawings in quantities. The former gives the better quality of reproduction; the latter produces copies more rapidly.
7. *Slide and film-strip projectors.* These two machines are commonly combined and may project either slides or film strips by slight adjustments. With a beaded screen, the room need not be darkened but it is well not to have the light intensity too high.
8. *Hand viewers.* A single pupil may view slides through one of these without disturbing the others in the class.
9. *Stereoscopic viewers.* These give the illusion of a third dimension to paired photographs. Some are designed for transparencies and some for opaque prints.
10. *Moving picture projectors.* Most moving picture projectors in schools today can also reproduce the sound on the sound track of films. They may also be used with silent films.

11. *Tape recordings.* Most tape recorders both record sound and play back recordings.

12. *Phonographs.* Modern phonographs play records at 78 RPM, 45 RPM, 33 RPM, and 16 RPM and have both large and small needles for standard recordings and microgroove recordings.

Fitting audio-visual aids into the curriculum. Despite the claims of enthusiasts, audio-visual aids do not call for new methods of teaching nor do they call for the elimination of already existing methods. Audio-visual aids should fit into the work of the class as a logical, sequential step in the learning process. One of the primary aims of the science teacher should be the integration of these aids into the over-all instructional program so that they are regarded by the pupils as the best possible way of learning about the topics under study.

One of the first considerations is to make certain that an audio-visual aid is not replacing a firsthand experience situation unnecessarily. It would be poor teaching indeed were a film on experiments with bar magnets to displace the experiments themselves. Audio-visual aids may supplement firsthand experiences but should not substitute for them save when the latter cannot be provided.

Another consideration is to make sure that pupils are ready to benefit from a specific audio-visual aid. They may not have the background needed for interpretation of a chart. They may not understand some of the words used in a sound film. They may not recognize the point of view from which a photograph is taken.

As to the type of audio-visual aid to be used, one must be governed by the situation. There is no one best type; a film is not necessarily better than a film strip, nor a model better than a chart. Sometimes one has advantages over the other and vice versa. Because all types have their limitations, and none are as good as reality, often the best solution is to use several devices together in hopes that the strengths of one will compensate for the weaknesses of another.

The timing in the use of an audio-visual aid must likewise be governed by the situation. When it is used to supplement a firsthand experience it must of course follow the latter. When used as a substitute for a firsthand experience, it can be used whenever the latter would have been used. In filling other functions it may come at any time; it may open a unit to set problems or it may end a unit to summarize it.

EDUCATIONAL FILMS

Educational films are used extensively and often indiscriminately in the classroom. Valuable though they may be within their limitations,

they are more subject to abuse than any other type of audio-visual aid. Perhaps this is so because a film temporarily takes over the task of teaching; teachers come to feel that the film is an independent device that can operate successfully without effort on their part. Some educators have gone so far as to claim that the film can replace the teacher, perhaps envisioning schools as movie theaters supervised by projectionists.

Actually, films can do no more than supplement the work of the teacher. Experiences provided by films are severely limited. Films are designed for mass instruction and cannot provide for individual differences; they cannot give pupils practice in problem-solving. Films should be classed in the same category as books and used in similar fashion.

Functions of educational films. Motion pictures are most useful in the classroom for helping pupils gain new experiences, necessarily vicarious in nature. In addition, they have a few other limited uses—presenting problems, providing overviews, summarizing learnings, and reviewing material covered. Few films can be used for all these functions; many are suitable for one function only.

1. *Overviewing a unit.* A few films are well adapted for use at the beginning of a unit to show pupils what the possible content of the unit will be. These films are especially helpful to initiate teacher-pupil planning sessions, especially if they suggest methods of attack on problems. A film used for overview should deal with situations and materials familiar to the pupils because as yet the pupils have gained no formal background in the subject. The language should be nontechnical for the same reason.

Miss Cruickshank chose the film titled, "The Cell—Structural Unit of Life" to open a unit on cells. The action of the film starts with two boys making a stained slide of onion tissue which they view with a microscope. They then view slides of other tissues, both plant and animal. The only technical words used are "cell," "nucleus," and "protoplasm," each of which is carefully introduced.

Following the showing, Miss Cruickshank asked for suggestions as to how the unit might proceed. One pupil suggested that they begin by making slides of onion tissue; the others voted for this approach. Then, feeling the need for more information about cells, they determined a general reading assignment by reference to the index in their textbook. The pupils decided to delay further planning until after they had used the microscopes and discovered some questions to be answered.

2. *Supplementing firsthand experiences.* The most important function of educational films should be to broaden understandings gained

by experiments and by field work. However, many films are constructed to accomplish too many purposes and are superficial in consequence. There are good films but not as many as one could wish.

Early in the fall Miss Thompson took her seventh grade class on a field trip to collect milkweed caterpillars. These were brought back indoors and kept in suitable cages.

The pupils had opportunities to see the caterpillars eat and move about. They saw one caterpillar forming a chrysalis and they saw a butterfly after it had emerged. But they did not see the butterfly emerge and spread its wings; there were other details of transformation that they also missed.

Miss Thompson then presented a film titled, "The Monarch Butterfly." The pupils already had a background of experience and a vocabulary suitable for appreciating the film, and the film answered many of their questions.

3. *Setting problems.* Although most films attempt to give solutions to all the problems they raise, a few films are well adapted to problem setting. In general these films deal with situations familiar to pupils, calling attention to things the pupils have experienced and awakening their interest in them.

Mr. Chesney presented the film, "Story of a Storm," near the beginning of a unit on weather prediction. This film describes the passage of a typical cyclonic storm over a community, describing the advance indications of its coming, the development of the storm, and its concluding phases.

During the discussion that followed, the pupils compared the storm described in the film with storms they had experienced themselves. In attempting to summarize learning, arguments grew so heated that a reshowing was necessary to satisfy everyone. Many questions remained unanswered, however, and these were listed for further study. Among these questions were:

1. *How fast does a storm move?*
2. *Why are cirrus clouds thinner than other clouds?*
3. *How low is the pressure in the center of a storm?*
4. *How can you tell when a cold front is coming?*
5. *What makes a storm start?*
6. *How does an aneroid barometer work?*

These and other questions were used in the organization of the work of the unit.

4. *Summarization and review.* Most of the commercial educational films are best adapted for summarization and review purposes. This is because they tend to deal with broad topics in superficial fashion. This superficiality is no special handicap if the pupils have already had

an adequate experience background and have drawn limited conclusions in advance.

Preparing to use a film. An activity that occupies fifteen or more minutes of class time should be carefully planned lest that time be wasted. Teachers tend to neglect planning for films because, unlike other activities, film showings present few discipline problems whether well planned or not. But class time is too valuable to be spent in an activity that provides only entertainment.

1. *Previewing the film.* The preview of a film indicates the best use to which the film may be put—whether it should open a unit, overviewing or setting problems, or whether it should be used later in the unit. From the preview the teacher may determine what preparation pupils need to benefit from viewing the film. He may decide upon preliminary experiences to be provided. He may list words that need careful introduction. He is able to decide upon follow-up activities that should come immediately after the showing.

2. *Using the manual.* Most educational films are accompanied by a manual that gives a synopsis of the film and usually suggests preliminary activities and follow-up activities. There is commonly a list of words to be studied and a list of suitable references. Teachers will find it useful to reread the manual in advance of later showings. The synopsis will refresh their minds about the contents of the film and the preparations needed, thus reducing the need for additional previewings.

3. *Making pupils ready for the showing.* Relatively few films should be used without preliminaries designed to make the viewing more meaningful to the pupils. Sometimes the pupils need firsthand experiences in advance in order to understand the significance of what they see.

Mr. Willis intended to use a film on the general subject of erosion, including an excellent section of animation showing the effects of frost action. To be sure that his pupils realized the expansion forces caused during freezing, Mr. Willis set up several days in advance an experiment showing the results of freezing a bottle of water in a mixture of salt and ice. He also encouraged his pupils to try the same experiment at home in their refrigerators.

Sometimes pupils need advance help with words. Technical words used in films commonly receive little or no special introduction but if pupils do not understand these words, they have difficulty interpreting the material in the film.

Mrs. Meyers wished to use a film featuring some excellent animation describing the fertilization of ovules. However, the term "tube nucleus," used by the narrator and as a label, would be unfamiliar to her pupils. Two days in advance of the showing she described the origin of the pollen tube and its function, introducing the term as she did so. The following day she reviewed the topic and the term. During the showing her pupils had no difficulty with the topic.

Sometimes pupils have never seen some of the materials shown in a film. They may have difficulty interpreting the pictures without help. The following technique was seen applied in an elementary classroom; there are times when it would be equally useful in science classes in the secondary school.

Miss Donahue was about to show a film describing conditions on some of the Pacific Islands. But first she displayed a coconut in its husk, some fragments of husk, some coconuts, and some palm fronds. She opened the coconuts to show the meat and the milk inside, and gave the pupils a little of each to taste. When the film was shown, the pupils were better able to appreciate the importance of the coconut to the inhabitants of the Islands than they had been previously.

To be truly effective, a film should help pupils solve problems of importance to them. One of the major advantages in having films always available is that they may be used whenever problems arise. However, rented films must be used during the short interval between arrival and required return. Sometimes the teacher can stimulate the thinking of his pupils enough to cause them to formulate problems.

A film describing experimental work with lightning in a high voltage laboratory became available unexpectedly. Mr. Fitch, the physics teacher, set apart a few minutes of class time for a consideration of lightning. His pupils raised a number of questions which he did not try to answer but which he asked the pupils to write down. He then set up the film projector and presented the film. Afterwards the pupils decided how many of the questions had been answered satisfactorily and which needed further investigation.

Sometimes teachers prepare a summary of a film and talk over with the pupils the nature of the film. Sometimes they list questions for the pupils to answer. There is some danger that these procedures will become formal and without challenge to the pupils. Much depends upon the nature of the topic of the film and the backgrounds of the pupils.

Showing a film. It is important that the presentation of a film proceed smoothly. Much time can be wasted bringing the image into focus, adjusting the sound, and arranging the framing. Whenever possible, the projector should be set up and tested beforehand, perhaps between periods. Sometimes it may be set up while pupils are busy with other problems.

It is usually well to let the first showing of a film proceed without interruption. The pupils should be allowed to concentrate fully upon the new material being presented. After the first showing many questions may arise. An immediate reshowing may be desirable. This reshowing may include the entire film but usually only sections pertinent to the questions need be shown.

Reshowings at later times may be used to follow up discussions and may be used for review. For these reshowings pupils may list questions to be answered or points to be noted. During reshowings it may be desirable to turn off the sound while the teacher or a pupil calls attention to important points. With some projectors it is also possible to stop the machine and project a single frame for special discussion.

Follow-up activities. Much of the value of a film results from what is done about it after the showing. A discussion period should always be provided. During this time pupils are able to ask questions about points that puzzle them and to refer to related experiences they have previously had. Because so many films end on a falsely positive note, pupils may not feel like asking questions. The teacher can stimulate discussions by asking a few questions about details given early in the film.

A short test using multiple-choice or true-false questions helps the pupils realize the extent and limitations of what they learned from the film. A discussion given after the test is often profitable. If problems have been listed, the discussion may center about how well the film helped solve them. A useful technique to be used occasionally is to conduct a review of the film, outlining the major points on the blackboard. Some teachers put this task in the hands of a temporary chairman and secretary.

If experiments have been described in the film and conclusions have been drawn from them, pupils should be encouraged to repeat these experiments to see if similar results are obtained.

An advertising film showed some remarkable characteristics of heat-resistant glass. During the follow-up discussion the physics teacher mentioned casually that through photography such results could be faked. The pupils became suspicious immediately and wanted to carry out the experiments themselves.

Commonly, certain phases of a film are not developed adequately because too much is attempted in the film. Attempts to follow up these topics may be more profitable than the viewing of the film itself.

A film on the life histories of some lepidoptera referred briefly to a caterpillar which eats aphids. Some of the pupils recognized immediately the unusualness of this habit and from their discussion came questions about other insects that are carnivorous. The teacher encouraged the pupils to plan an attack on this new problem.

Individual film showings. The showing of a film to an entire class presupposes that all the pupils will benefit from the film and are equally ready to view it. Such an assumption, of course, is completely unrealistic; pupils differ greatly from each other and cannot be equally ready or benefit equally from the viewing.

In rooms that have special work areas pupils with special interests may be permitted to view such films as are pertinent to their special interests. If the film is projected on a small monitoring screen, other pupils are not distracted; it is not even necessary to darken the room because the small image is very brilliant.

There are some practical difficulties to individualized showings. If the pupils are not qualified projectionists, the teacher must always be available to thread the film, start the machine operating, and rewind the film afterwards.

Selecting films for rental or purchase. The price of a film represents a substantial investment. Even rental charges add up rapidly. The selection of films demands careful consideration. All films should be previewed and, if possible, should be used at least once before purchase. Catalog descriptions and manufacturers' claims cannot be trusted to give true pictures of films. A good method for becoming acquainted with a film is to obtain a copy from a renting agency; the decision to purchase is then based upon actual trials.

When possible, films should be previewed before renting. There are usually film showings at teachers conferences and during summer session workshops. A card file of films listing titles and producers and commenting on general usefulness helps in choosing films for rent.

One of the first things to consider is the general *usefulness of the film*. The teacher should decide how and if he can use it. Commonly a film may be too difficult or too elementary for the pupils who are to see it. Producers' claims about grade placement cannot be trusted. It is also possible that the film cannot be related to the experiences of the pupils. Much of the film then becomes meaningless to them. Experience is the best guide in determining this characteristic of films.

A second point to be considered is *whether the film is worth the cost.* A film that merely describes experiments that the pupils could do in the classroom is certainly uneconomical. So too is a film that describes experiences the pupils have already had so often as to need no review. A film based on lengthy classroom discussion is apt to be of little worth.

A film may contain sections of valuable animation, time-lapse photography, or other special features. If, however, these take up but a small percent of the total footage, the remainder being easily duplicated in the classroom, the film under consideration becomes very expensive.

Color in films is often effective and sometimes absolutely necessary for the development of the content of the film. It is also expensive. If color adds nothing to a film except attractiveness, black-and-white films might better be purchased.

Sound has come to be accepted as a great asset to educational films. True, sound films have great potentials but they are rarely utilized. Few films use synchronized sound. Sound effects are occasionally dubbed in. Generally, however, the sound track is used only for the voice of a narrator who gives a running commentary on what is essentially a silent film. The narration is frequently not so useful as the teacher's own remarks, and some teachers simply turn off the sound and make their own comments.

A third point to be considered is the *technical quality of the film.* The pictures should be sharp and distinct. If there is color, the colors should be true; many copies are pale or lean heavily to the red end of the spectrum. The sound should be of good quality, with the narrator's voice distinct and understandable.

A fourth point to be considered is the *accuracy of the film.* Errors of fact often creep into films. Even when there are no errors there may be misleading ideas. The makers of a film are sometimes lacking in the scientific attitude and present theories as facts, draw conclusions from limited evidence, or making sweeping generalizations that cannot be justified. These weaknesses seriously impair the usefulness of a film.

Amateur films. Amateur films have the special advantage of being able to deal with local situations. Pupils have heightened interest and they quickly see the applications of the points made. The imperfections which are almost inevitable do not always detract from films and sometimes give it a more personal touch.

In the production of an amateur film the best procedure is to start with writing a script. Because the film is silent, the script is merely a

description of the desired scenes and of the needed subtitles. The scenes are numbered for convenience.

Then photography begins. Scenes are not necessarily shot in the order given in the script, but rather as is convenient. For instance, all close-ups of maps, posters and the like might be done at once so that the camera need be set up only once for this type of work. If, during the photography of the required scenes, unexpected opportunities for unusual scenes present themselves, these too are photographed. Later the script will be rewritten to include these scenes.

After the photography is completed and the film developed, some re-photographing may be needed to replace scenes that do not show up well. When all the scenes are satisfactory, the scenes are cut apart and spliced together in the order of the script. Titles and end matter are added. The film is now complete, faulty perhaps in places and obviously amateur work, but often far more valuable than a corresponding commercial film.

Mr. Jordan, a science teacher in a New England community, produced a film on the manufacture of maple syrup. Some of the scenes he shot while on field trips with his pupils. Some he took during special visits to local farms.

A film written, directed and produced by the pupils themselves has double value, partly from the teaching value of the film and partly from the experiences the pupils gain while producing it.

A science class in Greenwich, Connecticut, produced a film on the local water supply. The pupils carried out the needed research, wrote the script, planned the shooting schedule, and acted in many of the scenes. The school board supplied the film. One of the teachers did the camera work. The result was an attractive, informative film that was very useful in all science classes in the system.

FILMSTRIPS AND SLIDES

Filmstrips and slides are not to be considered as feeble substitutes for motion pictures. They are unique teaching devices, having certain virtues as well as limitations of their own. The chief advantage of these devices is their versatility. The teacher can alter the time allotted to any scene, or series of scenes, as he wishes. He can spend one second or ten minutes on one picture, using it as a focal point for discussion, as a model for sketching or drawing some object, or as a basis for oral test questions. In addition, the teacher can turn back readily to any scene for reconsideration. In the case of slides he may present the pictures in any order and delete those that are inappropriate.

Filmstrips and slides, when compared with moving picture films, are relatively inexpensive, and the projectors are far less expensive. The projectors are so simple to operate that all pupils can use them, either helping the teacher make a presentation or making presentations of their own.

The limitations of slides and filmstrips as compared with motion pictures are fairly obvious and need no detailed discussion. They do not compel attention as does the constantly shifting action of a film. The lack of motion, however, is not so much a disadvantage as a difference that allows filmstrips and slides to fulfill different functions.

Using slides and filmstrips. Filmstrips and series of slides may be presented in the same fashion as motion picture films. The pictures on film strips are arranged sequentially and they are commonly supplemented by captions that serve the same function as the narration of a sound film. Slides may be arranged sequentially and supplemented by oral remarks of the teacher. When slides and filmstrips are presented in this fashion, the same suggestions about preparation, showing, and follow-up as were given in the previous section on motion picture films apply.

Because of their versatility, slides and filmstrips may be used in several other ways, each with a specific purpose in mind. These visual aids may be tied in closely with other teaching procedures, perhaps to clarify a point.

During a description of growth changes in bones, Mrs. Mooney projected a single slide showing X-ray photographs of the hands of a child and an adult.

A slide may make it possible to illustrate an application immediately after a principle has been developed.

The physics class had completed several experiments relating weight and displacement of floating bodies. During the following discussion, Mr. Dixon projected a slide showing the Plimsoll mark on the side of a ship.

A few slides make possible comparisons that would otherwise be difficult.

The biology class had been shown calla lilies on a trip to a greenhouse in mid-winter, skunk cabbage blooms on a trip in late winter, and jack-in-the-pulpit blooms on a trip in early spring. To show that these plants are closely related, Mrs. Jorgenson projected slides of their flowers and called the attention of the pupils to the similarities of structure.

A slide may make an answer to an unexpected question much more meaningful.

John read in the newspaper that there was a good deal of sunspot activity on the sun at that time. "What's a sunspot?" he asked his science teacher. The teacher found himself beginning a vague verbal description but then remembered that in his files were some slides showing photographs of sunspots. He took but a moment to locate one of the slides, slip it in the projector and give a description that was understandable to John and the other pupils.

Slides showing diagrams are more conveniently stored than charts, though they cannot be made available for pupil use for so long a time. Sometimes a diagram on a slide is available when a chart is not.

To help give an understanding of a cathode ray tube Mr. Meade photographed a cross-sectional diagram of one. During the study he had on his desk a television tube and an oscilloscope. On the screen behind him he projected the diagram. By making references to the television tube and to the diagram, his demonstrations of the oscilloscope were made more understandable.

Slides of tables and graphs may also be useful. If the teacher knows how to prepare his own slides he can present material specifically designed for his purposes.

Mr. Meade found that his pupils had difficulty doing problems on relative humidity because they could not determine the necessary constants from the saturation curves he provided for them. So he photographed a copy of the curves and projected it on the screen. As he worked out sample problems, he could show his pupils the exact procedures to be used in reading the curves.

Mention was made earlier in this chapter of the difficulty some pupils have in interpreting diagrams. There are various techniques for making a diagram more meaningful.

Mr. Templeton was helping his pupils understand the development of a cumulus cloud. He projected on a large sheet of white cardboard a slide of a landscape with a prominent cumulus cloud overhead. With a black crayon he traced the direction of the air currents, and the level at which condensation was taking place. When he turned off the projector the paper contained a diagram very similar to the one given in the textbook.

Slides can be used for giving directions when verbal directions, either oral or written, are inadequate.

Mr. Clemens found that many pupils misinterpreted or ignored the verbal directions he gave for dissections, so he made colored slides of each of the

major steps. These were projected during the preliminary discussion of the directions. Then the corresponding slide was projected as pupils progressed through each stage.

Sometimes slides make excellent reviews. They may be used to review material presented through slides previously, in which case the same slides may be projected. Or they may be used to review material presented through firsthand experiences. The teacher who does his own photography has special advantages in that his slides can deal with the identical materials studied.

Field trips had been taken to see a number of topographic features caused by glaciation—kames, eskers, kettles, truncated spurs. On each trip Mr. Petty took colored slides of the things seen. During a review of the unit on glaciation, Mr. Petty projected the slides. The pupils identified the features and described their probable origin.

Slides may also be used for review tests in somewhat similar fashion.

A field trip to a nearby woodland introduced the pupils to a number of spring flowers. Mr. Mahon collected samples and put them on display. A week later he announced a test, asked the pupils to number their answer sheets from one to ten, and projected ten slides of wild flowers for the pupils to identify by name.

Pupils find slides and filmstrips useful when they are making reports on special investigations.

Susan and Joan choose to investigate the nesting habits of some common birds. They collected nests of some species but could not find materials to illustrate habits of nesting in cavities in trees, in tunnels in banks, and on the ground. Their teacher suggested they look at some of his filmstrips. They found one that was suited to their needs. During their report they used both their actual materials and the filmstrip.

Slides may be made available for individual study through the use of hand viewers. The slides may be studied as a follow-up of special interests or as part of a general assignment.

Mr. Burton gave to his earth science pupils sheets listing their assignments. The assignments called for a number of different activities including the study of a set of slides of sea coast features. The pupils were to identify each of these features by reference to photographs and diagrams in their textbooks, and then find out how each feature originated.

Handmade slides give pupils opportunities to prepare their own visual aids for use in making special reports.

Four boys in the seventh grade volunteered to present a report on the possible origin of the earth. The reference they used described the planetesimal hypothesis in some detail with free use of diagrams. The boys copied some of the diagrams on specially etched glass slides and colored the diagrams with crayons designed for the purpose. They based their report on these slides.

Building a slide and filmstrip library. The low cost of slides and filmstrips and the ease with which they may be stored makes it possible to develop a library that ranges widely in content and application. The immediate accessibility and the readiness with which they may be projected makes them of high value.

Filmstrips, compared with slides, are relatively inflexible. The pictures are arranged in a fixed sequence and supplemented by captions that present ideas according to a pattern devised by the producers. This makes it necessary for a teacher to evaluate filmstrips with special care. If he does not wish to present information as it is presented in the filmstrip, the strip becomes almost useless to him.

The philosophy of the producers is not always in accord with the accepted philosophies of science education. A number of filmstrips, for instance, are little more than reading lessons with the pictures supplementing the captions and at times being merely decorative. Commonly too these producers use paintings rather than color photographs. Sometimes paintings have special value but generally photographs are much more accurate and infinitely more realistic.

Slides are available from many sources. The large slides are generally in black-and-white and include both photographs and excellent diagrams. The smaller slides are usually in color and are often made from photographs. Slides may be purchased individually or in sets, the latter at reduced rates. However, a set of slides may contain slides of little or no use to the teacher; if this is so, the actual cost of the useful slides may be higher than when purchased individually.

Making slides by photography. The teacher who does his own photography has unlimited opportunities to build up his slide library. With a 35 millimeter camera the production of color slides is simple and relatively inexpensive. One need only follow the directions given on the packages of color film to produce successful pictures.

The purchase of a tripod and an inexpensive close-up lens enables a teacher to make close-up pictures of rocks, flowers, insects, leaves and the like. He may also copy maps, topographic sheets, charts, diagrams, paintings and colored slides. Books on photography give suggestions for this type of work.

Black-and-white slides may be made by printing negatives on

positive film. One may also take photographs on direct positive films which upon development give positive transparencies. The Polaroid-Land camera produces black-and-white transparencies a few minutes after the picture has been taken.

Handmade slides. Handmade slides enable teachers and pupils to prepare visual aid materials for special situations, and they represent a good medium of self expression for many pupils.

Several companies market kits containing the materials needed for slide making. The slides are invariably of the 3½ by 4 inch size, smaller sizes being difficult to work with. There are three basic types —cellophane slides, etched glass slides, and coated slides. Printed material may be typed directly on cellophane by the use of special carbon papers; these are bound between cover glasses for projection. With etched glass, line drawings may be made with a soft pencil and colored in with special crayons. Coated slides will take ink, thus giving sharper lines. The materials in each case are re-usable.

FLAT PICTURES

Flat pictures have a number of advantages and some serious limitations. Among their advantages is the fact that they are free or inexpensive, easily procured, and easily stored. They can be used for the study of very large or very small objects, and for objects that are unavailable in the classroom. In addition they commonly show objects in their natural surroundings. Flat pictures are excellent for individual study, either in the hands of the pupils or as part of displays and exhibits. They may also be projected on a screen for class study.

On the other hand, pictures are rarely true to color and commonly have no color at all. Size relationships are often not indicated and are sometimes distorted. The use of unusual camera angles may make interpretation difficult. Because of these limitations a teacher should choose flat pictures with care before attempting to use them.

Developing a picture file. Scattered through magazines and other publications is a wealth of material useful to science teachers. Some issues of the National Geographic Magazine and Life magazine are veritable treasure houses of valuable pictures. Catalogs, advertising brochures, and discarded books make other contributions. A number of industries print visual materials especially designed for teachers. The teacher who does his own photography may add to his collection by taking pictures in black-and-white and making enlarged prints. Standard 8 x 10 inch enlargements are a useful size.

Photographs and clippings may be stored in a standard letter file. Related photographs may be kept in a folder having a topic heading. The folders may then be filed alphabetically or under major headings that correspond to units of the course of study.

To prevent clippings from becoming creased and torn, it is well to cement the more useful ones to sheets of heavy paper or to sheets of thin card such as are used in laundered shirts. Pictures that are handled by the pupils are apt to become soiled. These may be mounted on cards and covered with plastic film. One excellent film is the type used to wrap meats before freezing. It is wrapped around the card and the edges are sealed together at the back with a hot iron.

Photographs or clippings used for individualized study may be stapled inside manila covers.

Using photographs and clippings. These visual aids are better adapted for individual study than for general class use. However, an opaque projector makes possible the projection of an image of a photograph or clipping on a screen where all may observe it. The uses then become identical with those of slides, discussed in the previous section.

Opaque projection is not as satisfactory as the projection of transparencies. The use of reflected rather than transmitted light results in a dimmer image. The more the room can be darkened the more visible the image becomes.

Photographs and clippings may be given out for individual study. Pupils need specific directions to guide their observations, perfectly written out so that they will not be forgotten while pupils wait their turn to examine the materials.

Mr. Williamson chose twelve colored photographs of birds to illustrate bill and foot adaptations. He stapled each picture in its own manila cover. On the facing side of the cover he stapled a typewritten sheet of questions to guide observations. The pictures were circulated during intervals of individualized work.

A similar technique has been used with stereophotographs. However, instead of circulating the materials, they are left in one place and the pupils take turns using them.

Mr. Schick purchased a set of stereophotographs illustrating successive stages in the development of a chick embryo. The photographs and the viewer were placed on a side table where the light was suitable for observation. The pupils were given guide sheets listing points to look for. They took turns looking at the pictures during portions of the period devoted to individualized work.

Bulletin board displays may be organized on the same basis. A set of guiding questions may be tacked to the bulletin board or copies may be given to the pupils. Copies given to the pupils may have spaces in which pupils are to write out their observations.

CHARTS

Charts are standard equipment in most science classrooms. They are used extensively by some teachers, little by others. The advantages of charts are several and make them desirable visual aids, but since their limitations are serious they should be used only with the greatest of care.

Advantages and limitations of charts. Most charts present a diagram or a series of diagrams. These charts may be difficult to interpret, because diagrams have such serious limitations. If the diagrams have been oversimplified, the pupils may not know what the diagrams are intended to represent.

When the limitations are recognized and provided for, charts have some distinct advantages. The diagram on a chart is generally superior to anything a teacher might draw on the chalkboard, providing visibility and contrast through prominent, sharp lines, bright colors, and bold printing.

Charts require fewer facilities and less effort for presentation than do lantern slides. Lines of diagrams are usually sharper and in greater contrast with the background. The chart may be left up as long as needed but slides cannot be projected indefinitely. Against these advantages must be mentioned the greater difficulty of storing a large number of charts.

Diagrams in textbooks and on duplicated sheets are much more difficult to follow during general discussion than are the diagrams on charts. A teacher may use a pointer to indicate each structure under consideration and lead the attention of the pupils from one structure to the next.

Using charts effectively. The first step in effective use of charts is the selection of suitable charts. Charts should always be large for general class use. All lines should be distinct and the printing should be readable from all parts of the room. Color is effective. It can be used to emphasize important details and to lead the eye towards them. On the other hand, too much color can be confusing, and nonfunctional color, applied for decorative effects, should be avoided.

Each chart should be simple and uncluttered, with adequate space between separate items. Some charts are so crammed with details that

from a distance, they resemble patchwork quilts. Some charts come with labels, some with parts indicated by letters or numbers. The latter kind are more versatile, since they may be used in oral reviews and testing.

Lighting should be considered when displaying charts. The best lighted wall should be used if the charts are hung on wall hooks. If a stand is used, it should never be placed so that pupils are looking towards the windows. A teacher should move about the room and check the visibility from several points.

The major limitations of charts can be compensated for by proper planning. The solution is often simple—pupils must know what they are seeing when they look at a chart.

Mr. Clair set up a large spark coil and produced sparks so that the class could recognize its function. He then displayed a chart on which was a cross-sectional diagram of a spark coil. Before attempting an explanation of the action of the coil, Mr. Clair took time to point out on the chart each visible feature of the apparatus. He then indicated where the interior structures shown on the chart were located in the apparatus.

Sometimes it is feasible to put materials in the hands of the pupils before beginning a study of diagrams on charts.

Mrs. Dayton's biology class collected grasshoppers on a field trip. For the next class period each pupil had a live specimen in a jar. After the pupils had looked casually at their grasshoppers, Mrs. Dayton hung up a chart on which were two diagrams, one of the external anatomy of the grasshopper and one of the internal anatomy. Pupils studied the external anatomy first, comparing their specimens with the chart. Attention was then given to the diagram of the internal anatomy so that the pupils could relate some of the internal features with the exterior.

As the above illustrations show, charts have important uses in supplementing demonstrations, discussions and the like. They may also be used for review.

Mrs. Tatum displayed three charts with diagrams representing the life history of a fern, a moss, and a mold, respectively. She gave the pupils duplicated sheets of questions which referred by number to the structures on the diagrams. She asked the pupils to answer these questions.

Charts may be used in similar fashion for testing pupils. It is important that they have studied the same charts before so that they are familiar with the conventions used in making the diagrams.

Mrs. Tatum asked her pupils to write down in order the ten numbers she dictated. She then displayed a chart on which the same numbers referred

to structures in the human eye. She asked the pupils to write down the names of the structures indicated by these numbers.

Making charts. Sometimes teachers wish they had charts for special purposes but find none available at scientific supply houses. They can make these charts with relatively little trouble. For temporary use, charts may be made by using a felt pen on large sheets of wrapping paper. These charts are not very durable and are easily damaged during storage. Longer lasting charts can be prepared by making drawings on sheets of white poster board.

Permanent charts are made on special chart cloth sold by scientific supply houses. Outlines are drawn in pencil and traced in India ink with a ball-tipped pen, a drafting pen, or a felt-tipped pen. Colored lines, labels and arrows may be added with colored drawing inks. Colored areas may be filled in with wax crayons, after which the wax is blended in by applying a warm iron to the reverse side.

An opaque projector is of great help in laying out a chart. The chart cloth is tacked to a bulletin board in a darkened room. A diagram from a book or a clipping is put in the projector and focussed on the cloth. By moving the projector to and fro, the size of the image can be varied until it fills the desired space. The outlines are traced in pencil and can be inked later. Chart making is an excellent project for pupils to carry out either as a service to the teacher or as part of presentations which they themselves plan to make.

MODELS

Models tend to be superior to many diagrams and pictures, because they introduce a third dimension. They possess some of the same limitations, however. If pupils do not understand what the models represent they cannot interpret them.

Models fall into different classifications. Scale models are designed to duplicate the appearance of a real object as closely as possible, but are usually larger or smaller. Diagrammatic models emphasize selected features and suppress others for the sake of clarity. Display models show structural characteristics and operating models show the action of moving parts.

Choosing models for classroom use. A model must be of adequate size to be seen clearly from all parts of a room if it is to serve as the center of class discussion. Smaller models may be used for individualized work. Generally speaking, a model should be three-dimensional, although there are exceptions in the case of some cross-sectional

models. The value of a model lies in its presentation of the parts in their proper spatial relationships.

The degree to which a model resembles the real object is important. Simplification is desirable, but it is possible for a model to be oversimplified. The subject of the model and the age level of the pupils with whom it is to be used must be taken into consideration.

Using models effectively. Pupils commonly lack the type of background that makes interpretation of a model possible.

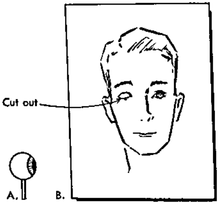


FIGURE 10. *Pupils often have difficulty in visualizing the relationship of anatomical models to corresponding structures in their own bodies. The model of the eye is usually shown to pupils, as in A, with no relation to the head. If a teacher draws a face on oak tag and cuts out one of the eyes (B), he can show the relationship by holding the model behind the cut-out in the proper position.* (From Patricia Birdsall, "Making an Eye Look Like an Eye," *School Science and Mathematics,* November, 1950.)

Mr. Corbin purchased a cut-away model of a gasoline engine. As the flywheel of the model was turned, the pistons moved up and down, valves opened and closed, and lamps flashed to simulate the sparking of the plugs. Pupils were fascinated by the model and operated it whenever he would let them.

A test given at the end of the unit, however, gave no better results than formerly. Mr. Corbin talked confidentially with some of the pupils who had failed the test and discovered that they still had no true concept of pistons, cylinders, and crankshafts and they were puzzled about the lights in the model. The following year, Mr. Corbin took the pupils to see an engine block in an auto supply store. He also replaced the lamps in the model with improvised spark plugs that sparked when an induction coil was used. His pupils now interpreted the model much more satisfactorily.

Similar problems of interpretation are apt to arise with the use of biological models, especially those that deal with microscopic sections.

For several years Mr. Arthur used a large model of a three-year-old woody plant stem without much success. One year he reversed his technique for introducing the model. He took the pupils on a field trip to collect specimens of one- and three-year-old saplings. Back in the laboratory the pupils compared sections of their specimens, summed up their observations, read

about woody plant growth, and discussed their learnings. Only then did Mr. Arthur bring out the model. This time interest was high and pupils studied the model carefully.

There are various techniques for helping pupils relate anatomical models to reality.

Miss Birdsall drew on heavy card an outline of a face, using the same scale as the eye model she intended to use. She cut out one eye from the drawing. By placing the eye model at the edge of a table and holding the cardboard in front of it, the relation of the visible parts of the eye to the remainder of the face could be seen and the relation of the invisible parts could be inferred (see figure 10). Miss Birdsall used a similar technique with an ear model, drawing a head in profile and cutting out the ear section.[1]

Making models. There are certain advantages to making models. One is the reduced cost; commercial models are generally expensive. Then too models may be made to fit specific situations; an earth science teacher may prepare a relief model of the area around the school, which he could not purchase from supply houses.

Probably the chief value of model making is the construction of models as special projects. The research necessary for the production of a good model adds greatly to the development of scientific concepts. The skills developed are generally worthwhile. And the satisfaction gained is invaluable in developing desirable attitudes.

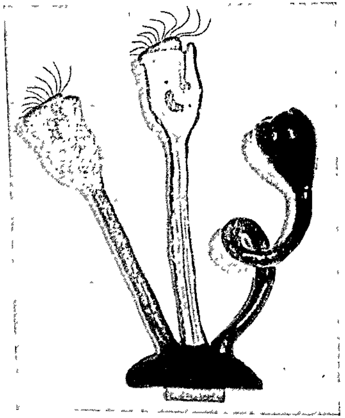
Modeling clay has several uses in the biological and earth sciences. It may be used for figurines illustrating evolutionary development, for models of anatomical structures, and for illustrations of land forms. Plasticene, which comes in several colors, has similar uses, and the combination of two or more colors gives contrast and often increased realism.

Plaster of Paris is a versatile material. It gives sharp castings; it may be drilled, sawed, and sanded; it may be tinted and painted. It is excellent for permanent models, although it chips easily and requires careful handling and storage. It may be used for casting animal tracks found in mud, for making reproductions of small objects, and for reproducing objects in relief on plaques. Blocks of plaster are easily sculptured before the material has completely hardened.

Several plastics useful for modeling are marketed by scientific supply houses. These are relatively expensive but have special uses that make them worthy of consideration.

[1] Birdsall, Patricia, "Making an Eye Look Like an Eye," *School Science and Mathematics*, November, 1950.

Mechanical models are usually made of wood and metal. Supplies of these materials and the tools needed to work with them should be a part of every science classroom. Construction kits of wooden and metal parts have innumerable uses; although sold as toys they are truly educational and deserve a place in the science program.



This model of a protozoan was first made with clay, which was then coated with liquid latex. After setting, the latex was stripped off and became the mold in which plaster of Paris was poured. The plaster model was finished with oil paints.

RECORDS AND TAPE RECORDINGS

At present there is only a limited library of records that reproduce natural sounds such as waves on a beach, jet planes, frog calls, and the like. The most successful of these have been the recordings of bird calls and songs. Teachers use the latter to help pupils learn to identify birds by their songs. Commonly they play the records and at the same time project pictures of the corresponding birds on a screen to enable pupils to associate both sound and sight. Undoubtedly this technique could be used for other recordings.

Recordings of musical instruments may be used in science classes to study changes in pitch and the quality of sounds produced by different types of vibrating materials. For physics students there are records designed to help test the fidelity of phonographic equipment; such testing helps pupils develop understandings of the characteristics of sound.

Many musical masterpieces are based upon the sounds of nature. Perhaps these could be used more in the science program to add to the interest of the subject and to the meaningfulness of music. For instance, the section depicting a storm in Rossini's William Tell Overture could be compared with the sounds of a real thunderstorm and its sequence analyzed.

The portable tape recorder is a versatile machine that enables one to pick up sounds almost anywhere and reproduce them at will. Science teachers can make good use of them.

Mr. Bradshaw, a student teacher, was teaching a unit on weather to an eighth grade. To emphasize the west to east movement of storm fronts in the region, he took tape recordings of the "Weather Round Up" of the New York State Rural Radio Network. Stations beginning at Buffalo and ending at Albany reported on the local weather. If a front was passing over the state there were marked differences in weather to the east and the west of the front. Soon Mr. Bradshaw had a number of good examples to play to his pupils.

Some of the best science broadcasts are given evenings or weekends. Even when these are broadcast during the school day the number of pupils who can listen to them is limited. Tape recordings made of these broadcasts can be played over and over.

The pupils in one science class can produce a radio program or a play which is then recorded and played to other sections. Pupils gain practice in language arts in the process. Some elementary teachers have sent their tape recordings to pupils in distant schools with whom they have correspondence. Perhaps this would be an interesting project for science clubs.

Tapes are easily edited; portions can be clipped out with a razor blade and the ends spliced with cellulose tape. Or the tape may be cut apart and another section spliced in. Editing gives the tapes additional versatility.

Mr. Wilson wanted to play the songs of a limited number of birds. He prepared a tape recording from all his records and cut out the sections that he wanted. These he spliced together in the order he thought most useful.

large enough to attract attention. It should be arranged with artistic unity.

Displays should be topical; that is, centered about a theme. A mere display of unrelated materials is rarely interesting or of much educational value. The theme may be one related to class work or it may be independent, representing a matter of current interest or of special interest to certain pupils.

A display may illuminate class work but it should rarely try to duplicate it. A flow chart of the Solvay process in colored poster paper may be striking, but if the textbook contains exactly the same flow chart the utility of the display may be questioned.

It is important that displays be changed frequently. Nothing is more depressing than a faded or dust covered exhibit. Pupils develop a habit of looking at displays only when they expect to see new things regularly. The preparation of new exhibits may be done by the teacher, but there are many valuable outcomes for pupils when the latter prepare exhibits. The task of arranging a new display may be assigned as a group responsibility replacing other assignments or it may be suggested as voluntary work for extra credit.

The bulletin board. The bulletin board is best adapted for displays of pictures and clippings though other flat materials may be attached where there is no danger of their being brushed off. Most classrooms today have some bulletin board space but there may not always be enough. The area above the chalkboards may be used for some types of displays. Strips of composition board to which pictures may be tacked, or strips of decorators' burlap, to which pictures may be pinned, are attached above the chalkboards and used for poster materials and large, uncluttered pictures.

Unused sections of chalkboards may also be used for bulletin boards. Materials are attached with masking tape. The use of the chalkboard has additional advantages in that lines, labels, and diagrams in colored chalk may be used to amplify and to give emphasis to the materials displayed.

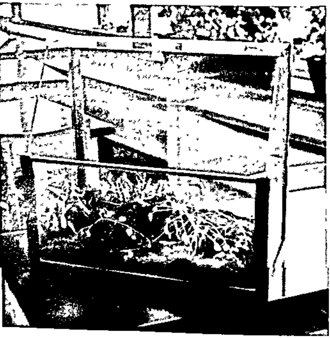
The preparation of bulletin board displays may be an outgrowth of regular class work; sometimes it can be planned to be an integral part of such work.

Mr. Marshall's eighth grade science class was engaged in the study of airplanes. Mr. Marshall suggested that a bulletin board display be prepared. Several pupils made suggestions none of which were accepted by their classmates, either because the materials would be too familiar to everyone or because the materials would not have sufficient appeal. Finally the class decided to prepare an exhibit based on famous trans-Atlantic

flights. Committees were organized to do the necessary research, to find pictures in Mr. Marshall's files, and to draw maps and labels.

Pegboards. Pegboards, designed for storage of merchandise and household items, can be useful in the classroom for displays of teaching materials. These pegboards are drilled at regular intervals to receive hooks, shelf holders, tool holders and other special adaptors. When a board is fastened to a wall it should be separated slightly from it by means of cleats or by separators designed especially for the purpose. The boards come in several colors but they may be finished in enamel over a primer coat.

Items for display may be suspended from hooks. They may also be placed on shelves of thin plyboard which are held up by shelf supports provided for the pegboards. Obviously, one of the major advantages of the pegboard is the ease with which the various holders and supports can be rearranged to meet the special needs of the display.



Many styles of small display cases can be constructed of glass panes and adhesive tape. This case is being used as a terrarium for plants that need high humidity. Similar cases can be used for the exhibit of fragile specimens.

Display cases. Small cases, about 12 to 18 inches on a side and 9 to 12 inches high, may be used for display of specimens that should not be handled or exposed to dust. These cases may be made of a variety of materials: Lucite, Plexiglass, celluloid, or sheet glass. The plastics

may be cemented together. The glass may be held with adhesive tape. These cases are especially useful when all sides of a specimen are to be viewed.

Wall cases. Wall cases which may be closed and locked are needed for the display of fragile and expensive specimens. Generally, shallow cases are most convenient. A viewing area unbroken by frames is desirable. A pegboard used at the rear of the case makes possible many arrangements of the supports used to hold the specimens.

Interior lighting is especially desired; fluorescent lamps across the top, with a shade to keep light from shining directly into the viewer's eyes, are most satisfactory. When shelves are used these should be of glass or clear plastic to reduce shadows cast on specimens beneath.

In museums one will see a number of techniques that may be adapted to making the displays in wall cabinets more effective. Rectangles of colored paper placed under or behind specimens give emphasis and provide needed contrast. A mirror behind a specimen makes its rear surface visible. A large lens properly mounted magnifies a small specimen or a portion of a large one. Colored threads may lead from parts of a specimen to labels and captions or to related specimens.

Display tables. Any science classroom is improved by the addition of a display table. On this may be placed large specimens, models, and other materials that may be handled. One important use of the table is for the display of apparatus used during a demonstration so that the pupils have opportunities to examine the material closely and manipulate it.

A small bulletin board behind the display table adds to the table's versatility. On the board may be pinned pictures, descriptive materials and directions pertinent to the display.

The chalkboard. The chalkboard is a familiar and much used teaching device but it is to be feared that it is often used carelessly and without full realization for its potential. Certainly the crude scrawls and aimless scratchings seen on so many chalkboards must have little teaching value.

The use of the chalkboard should be planned as carefully as a demonstration or a test should be planned. The chalkboard is too important to be left to chance or to spur-of-the-moment inspiration. The teacher should decide in advance just what parts of a lesson are to be presented by means of the chalkboard. He may find it useful to make a layout of this material on a sheet of paper so that he can determine in

advance the amount of space required, the best means for emphasizing certain points, and the details of spacing.

Carelessly-made diagrams may be worse than useless. In some instances it is wise to make diagrams in advance, laying them out carefully, and emphasizing points with colored chalk. Advance construction makes possible a check on visibility from various parts of the room.

Sometimes a teacher wishes to construct a diagram a bit at a time while explaining it to the class. He may draw the diagram in advance with soft chalk which on erasing leaves a vague outline. The teacher may then reproduce the outline as he wishes.

Accessories that help realize the potential of the chalkboard are a blackboard straightedge, a blackboard compass, a blackboard protractor, a blackboard 30-60-90 degree triangle, and a blackboard 45-45-90 degree triangle. A section of the chalkboard should be ruled off into squares with a carborundum or hardened steel stylus to facilitate the construction of graphs. A teacher who has difficulty with blackboard writing will find that lightly ruled lines on a section of the board will help him level and space his writing better.

Displays using colored chalk and built around diagrams or pictures taped on the board can be very effective. Sections used for this purpose should be those that are not used regularly during class presentations.

Suggested activities

1. As special projects, make (1) a chart; (2) a plaster of Paris cast of a track; (3) a handmade lantern slide; (4) a working model; (5) an anatomical model; (6) a diorama.

2. Analyze a motion picture film carefully to determine the length of the portions that (1) duplicate or review experiences pupils have already had, (2) provide experiences that could well be provided at firsthand by the teacher, and (3) provide experiences that could not well be provided otherwise. Using the total cost of the film determine the cost-per-foot of the portion that justifies its purchase. Compare several films on this basis.

3. Study a film carefully and make plans to use it wisely, with provisions for whatever background (including firsthand experiences) is needed for its interpretation and follow-up activities to add to the effectiveness of the film.

4. Prepare an attractive and meaningful bulletin board display. Submit it to the criticism of others in your science methods class.

5. Begin a file of flat pictures.

6. Practice using the chalkboard effectively including the making of diagrams, straight writing and printing.

7. Assume that you are to show a class a filmstrip or a set of slides. Write out the comments you would make for each frame in the strip. Present this to the methods class.

Suggested readings

Dale, Edgar, *Audio-Visual Methods in Teaching*, Dryden Press, New York, 1954.

Dent, Ellsworth, *Audio-Visual Handbook*, Society for Visual Education, Inc., Chicago, 1949.

Emmert, W., "Standards for Selecting and Evaluating Still Pictures," *Educational Screen*, December, 1937.

Heiss, E. D., Obourn, E. S., and Hoffman, E. W., *Modern Science Teaching*, Macmillan, New York, 1950.

Hoban, C. F., Hoban, C. F. Jr., and Zismar, S. B., *Visualizing the Curriculum*, The Dryden Press, New York, 1944.

McKown, H. C., and Roberts, A. B., *Audio-Visual Aids to Instruction*, McGraw-Hill, New York, 1949.

Science Education in American Schools, Forty-sixth Yearbook of the National Society for the Study of Education, Part I, University of Chicago Press, Chicago, 1947.

SCIENCE TEXTBOOKS, NOTEBOOKS, AND WORKBOOKS

chapter 9

The textbook is the most widely used of all teaching instruments, not excepting the teacher's own oral presentations. Indeed, the textbook is almost synonymous with schooling. Few teachers attempt a program without one and many administrators require that one be used. Student notebooks are likewise well established teaching devices and in widespread use save where replaced by their printed equivalents, workbooks.

Any devices used as extensively as these are certain to be misused on occasion and to be the subject of harsh criticism in consequence. But the criticism should be leveled at the way they are used rather than at the devices themselves because each has certain merits that makes it useful in the science program.

These devices may also be overused. It is important to remember that textbooks, notebooks, and workbooks are but three of the many tools available to the science teacher. There is no justification for allowing one to dominate the program. Over-dependence upon the textbook, for instance, limits the program to the advantages possessed by the text and excludes the advantages unique for experiments, films and projects. Well-balanced utilization of all the tools of science teaching gives pupils the advantages of each.

SCIENCE TEXTBOOKS

The concept of the textbook has changed greatly in the last century. Once used chiefly as a source of information, the textbook has today

become a course of study, a set of unit plans, and a learning guide as well. Once employed most commonly in the textbook-recitation method, it is today employed in many other and more stimulating ways.

Structure and function of a science textbook. The modern science text is a complex publication. Its characteristics can be discovered only by careful study and by classroom use. The present-day textbook is usually divided into sections which are roughly analogous to chapters. But these sections are more than chapters, they are unit plans built around specific topics. Thus a textbook becomes a course of study which may be used in its entirety or with such additions and deletions as a teacher may wish to make.

The book invariably begins with an introductory section that may overview the contents of the book, attempt to define science, describe the scientific method, and illustrate the scientific attitude. Thus the book attempts to set the stage for the year's program.

Each section or unit opens with provision for some activity that readies the pupils for the work to follow. This might be a pretest to acquaint pupils with the extent of their knowledge. It may be a recall of past experiences to establish the foundation upon which later learnings will be built or a brief historical background to show the developments that have led up to present knowledge. It may be a discussion designed to establish problems for the pupils to solve.

The body of each section more closely resembles the body of a typical chapter. It provides printed information and is supplemented by photographs and drawings. Captions given with the illustrations may be informative, they may suggest ways to study the illustrations, or they may ask questions about them.

Textbooks commonly include in the body of each section many suggestions for supplementary activities: experiments, demonstrations, readings and the like. These are tied in closely with the printed matter.

Each unit ends with at least one special feature. There are always questions for self-evaluation. There may be a list of expected learnings and a list of technical words used. Commonly there are suggestions for additional experiments and projects.

A few textbooks supplement each unit with material in boxes and with footnotes. The boxes may contain short biographical sketches of scientists or accounts of the history of specific scientific developments. Footnotes are used chiefly to give the meaning and pronunciation of technical words.

Science textbooks invariably close with an index. Sometimes there is a glossary. Occasionally there is a concluding review section with provisions for self-evaluation.

Considerations in use of textbooks. Textbooks tend to be general and comprehensive. They must be written for nation-wide sale and therefore deal only with topics of nation-wide interest. A teacher cannot depend upon a text for a complete program without sacrificing the contributions that may be made by the study of topics of local or immediate interest.

Textbook editors, concerned lest their books be criticized for omitting material of interest to any potential buyer, encourage authors to touch upon every conceivable topic. Textbooks therefore tend to contain more topics than a class can deal with adequately in one school year. Any attempt to "cover the text by June" results in superficiality. Teachers must learn to omit sections.

The very inclusiveness of a text forces its authors to deal largely in generalities. They have not the space to deal adequately with the facts upon which the generalities are based, and they cannot point out exceptions and limitations. Neither do they have the space to discuss theories sufficiently, giving the evidence that supports the theories and the assumptions that are involved. In consequence, textbooks give the impression that science is represented by an infinite body of known facts and unquestioned principles, rather than by a few facts, some doubtful conclusions, and many unsolved problems and unexplored areas. Teachers must learn to point out constantly the distinction between what is certain, what is doubtful, and what is completely unknown.

Textbook authors have an unfortunate habit, perhaps encouraged by editors, of giving the outcomes of all experiments and the solutions to all problems. The teacher who wishes to give his pupils practice in problem solving cannot depend upon the text for this function, but must encourage pupils to raise their own problems and find ways to solve them.

In using a text, a teacher must give consideration to the reading level of his pupils. As shown in chapter two, the range in a group may be great; some pupils read with difficulty and are reluctant to turn to books. Advanced readers, of course, can use texts from the beginning. Retarded readers will need special help.

Using unit introductions. Authors of textbooks design the introductions of the units to stimulate curiosity and establish problems. Such motivation is far superior to plunging pupils into a study of material for which they see no purpose. The introductions given in the textbooks cannot be considered as ideal. Authors are handicapped in preparing these introductions. They must write for nation-wide usage and cannot take advantage of strictly local or momentary conditions. In consequence,

there are usually more satisfactory introductions that can be devised by a teacher to fit his local situation.

A reference to a local event or condition in which pupils are interested may stimulate a lively discussion out of which grow problems pupils are anxious to solve. At other times, a demonstration, a field trip or a film may produce strong interest. The teacher will do well to examine each unit introduction carefully and try to devise a more challenging approach. Perhaps he will find such a substitute but sometimes he may find the textbook approach ideally fitted for his specific needs. Sometimes the textbook introduction has more value after the teacher's own introduction and may follow closely afterwards. Sometimes it can be assigned as special reading or used during the review and summary that ends the unit.

The problems with which an author opens a unit need careful examination also. These problems are necessarily broad and may be far removed from the lives of the pupils. Many of them are useful in the local situation. Others have little value and can well be replaced by problems that apply directly to the interests and needs of the pupils.

The textbook unit was headed, "How do communities get their water supply?" and was introduced by a general discussion of the need for safe drinking water in large quantities. Mr. Foster changed the problem to "How does Pottsville get its drinking water?" He introduced the unit with a trip to the water treatment plant, and set up sub-problems in terms of the observations made on the trip.

Reading-recitation techniques. This is probably the oldest of the techniques used with textbooks. It was once used so extensively that it was titled the "textbook-recitation method." As the term indicates, pupils read a section of the textbook and then recite their learnings. Employed occasionally for brief periods it can be effective. Employed indiscriminately day after day, as it once was, it stifles individual initiative and kills interest.

Reading-recitation may be used to emphasize sections of the text that are considered highly important, and should be reserved for this use. To employ it for trivial information reduces its effectiveness in other situations.

The teacher should be certain that the material to be read can be interpreted by the pupils, so that their time is not wasted. If the language is too difficult or the ideas too complex, other forms of presentation should be employed instead. Sometimes it is advantageous to use the reading-recitation technique near the close of a unit, when the pupils have gained a suitable vocabulary and an adequate background for understanding.

Instead of following the reading of the text by pupil recitation or by oral questioning, a teacher may find group discussion more profitable. A pupil may recite on what he read, then other pupils comment on his statements, describe their related experiences, and criticize the generalities given in the book. Commonly from these discussions of the information given in the book arise problems that the pupils are anxious to solve.

Pupil presentations of textbook material. A teacher may delegate to a group of pupils the responsibility for presenting a section of a textbook unit to their classmates. The pupils use the same demonstrations, perhaps supplemented by additional ones, and charts or models based on textbook illustrations. They call for textbook readings and assign special problems.

Occasionally a full unit lends itself to division into sections each of which can be assigned to a group.

Mr. Kenny divided his physics class into six sections for the study of simple machines. Each group was assigned one section of the textbook unit with instructions to prepare a presentation for the class. The pupils followed the pattern of the text, using demonstrations, experiments, charts and film strips Each group worked out problems on the blackboard, assigned problems and corrected them, and prepared a final quiz.

Reading assignments in the textbook. Teachers customarily make uniform reading assignments in the basic textbook. There are times when these assignments are justified. The material covered by the assignment should be of high importance to all pupils. The pupils should recognize the importance of the material and desire to read about it. The language and the ideas presented should be simple enough for all pupils to be able to interpret. Unless these three conditions are met, the reading assignment is apt to waste pupil time and discourage interest.

Reading assignments are more profitable if pupils know in advance what information they are supposed to be finding. The teacher may prepare a list of questions to be answered. The questions help the pupils sift from the mass of details the items that the teacher considers most important. When possible the assignment should be based on a problem which the pupils are anxious to solve. The pupils themselves may prepare a list of questions to be answered by the reading.

Assignments need not be uniform. Individuals or groups may be given different lists of questions to answer. These pupils then report back to the class on their findings which they attempt to make meaningful by explanations and visual aids of various types, including the

illustrations in the textbook. Later during review all pupils may be expected to read the same section. This practice helps pupils gain the necessary vocabulary and background to understand the assigned material.

Using suggestions for demonstrations and other activities. When a textbook gives directions for demonstrations, experiments and similar activities, it is possible for the pupils to work with a minimum of guidance from the teacher. In some instances, each pupil working alone or with others may carry out the directions. Sometimes it is better to ask groups to set up equipment and present demonstrations to the class. In this last case, one group may work apart from the class during class time or it may work during free time to make preparations. Occasionally, when there are enough suggestions, the class may be broken into groups, each of which presents a demonstration.

It is unfortunate that most authors give the outcomes for the experiments suggested by their books. By doing so they make impossible the discovery approach to science with these particular activities. A teacher may, however, think of variations on the suggested experiments and thus encourage activities in which the outcome is not known.

The textbook suggested that a metal can be filled with a mixture of water, ice, and salt to produce condensation on the exterior and thus show that cooling the air sufficiently causes condensation. After the demonstration and the following discussion during which pupils stated the expected principle, the teacher interjected, "Maybe the water soaked through the can somehow." Though the pupils did not think that it did, they were challenged to set up an experiment to see whether such might be the true explanation.

Using the illustrations. The illustrations in a textbook are commonly among its strongest features and should be utilized as fully as possible. Many photographs and diagrams deserve extended attention with discussion of details and applications.

Sometimes an illustration can be used to establish a problem for solution. Perhaps the pupils want to know how a device operates or perhaps they can be challenged to find out why a certain reaction occurs. Photographs showing unusual adaptations of organisms may stimulate pupils to do further reading about the life histories of the organisms. The illustrations may show applications of principles learned in class work and pupils may be encouraged to discover how the principles apply.

for better control of the discussion. Pupils may sometimes take the responsibility for the presentation.

The textbook showed an illustration of a concert harp. Georgianna, whose aunt played this instrument, volunteered to explain the photograph. She used an opaque projector to give an enlarged image on the screen and then pointed out the pegs for tuning the harp and the pedals used for changing the key of the harp.

The illustrations may be used during review. As the pages of the text are turned, the teacher calls on the pupils to explain certain features in each illustration.

Utilizing historical and biographical sketches. Some science educators believe that a knowledge of the historical backgrounds of science gives increased knowledge of the present day status of science. Some go so far as to recommend a recapitulation of the major developments of science. Generally the sketches given in textbooks are too brief to paint vivid pictures. These may be used as beginning points from which interested pupils go to encyclopedias, biographies, and books on the history of science.

Textbooks as references. Textbooks may be used for references, but usually the information contained in them is condensed and general. If the books are so used it is best to encourage pupils to follow their readings in the text with references to encyclopedias and specialized books or articles. The text helps them gain an overview of the topic.

Textbooks for summary and review. This is one of the strongest uses of the textbook. After a unit has been completed, and the pupils have taken several field trips, carried out many experiments, and looked at numerous visual aids, the textbook brings together their learnings and summarizes them in meaningful fashion.

A textbook lesson. The following is an illustration of the way in which a physics teacher built a complete lesson about a section of the textbook. It is given as an example of one of the many uses of the text but not as a recommendation for daily practice.

Mr. Austin had asked his class to review the textbook material on the energy relations involved in evaporation and condensation. He opened the class period with a brief test to focus attention on this topic. He turned next to the subject of the day's lesson—mechanical refrigeration. He drew attention to the refrigerating unit he had taken from a discarded refrigerator and helped the pupils visualize its location in the cabinet by reference to a large chart of a refrigerator.

Mr. Austin then directed the pupils to open their textbooks to the appropriate section. Because he considered the subject difficult, he asked the pupils to take turns reading the section aloud while he pointed out on the chart and the actual unit each structure as it was referred to. He also asked the pupils to find the same structures on the diagram in their texts.

Brief questioning quickly revealed a number of uncertainties despite the care he had used to deal with the topic. This led to a general discussion and frequent references to the text. To make a final summary one pupil reread the section aloud while another pointed out the structures on the chart.

Mr. Austin described the variations that could be expected in home refrigerators. He asked the pupils to take their textbooks home with them and compare the diagram and information given with the refrigerators in their kitchens.

He then raised the topic of other applications of mechanical refrigeration. Among those suggested was air conditioning. A brief discussion of this last topic raised several questions that interested the pupils. Mr. Austin asked the pupils to read about this topic in their textbooks as a background for the next day's work.

Helping retarded readers with the textbook. Were science textbooks written for the norm of the grade in which they were to be used, the half of the pupils below the norm would have trouble with the books. Some could not read the books at all; others would have difficulty with them; many would use the books reluctantly.

There is some evidence that textbooks are truly difficult. A recent study of physics textbooks brought forth the following conclusions:

1. The reading levels of many textbooks are too advanced for the students for whom they are written.
2. The failure of many students to achieve in subject-matter areas can be caused partly by the levels of reading difficulty of the textbooks in these areas.
3. The levels of reading difficulty of textbooks within any subject-matter area differ greatly.
4. Teachers should select textbooks using the levels of reading difficulty as a criterion.
5. Publishers need to take greater cognizance of the levels of reading difficulty of the textbooks they produce.[1]

Pending further investigations it seems reasonable to extend these conclusions to apply to other texts. Authors of science textbooks are rarely reading specialists; they use a technical vocabulary and concise writing that causes difficulty for young readers. It is to be expected

[1] Mallinson, George G., Sturm, Harold E., and Mallinson, Lois M., "The Reading Difficulty of Textbooks for High School Physics," *Science Education*, February, 1952.

to all of them.[2] Choice must usually be based, therefore, upon the remaining differences.

The following factors should be considered in evaluating content: (1) the content should be appropriate for the age level and experience backgrounds of the pupils; (2) the concepts should not be too complex for the maturity of the pupils; (3) the content should be consistent with the pupils' needs and interests; (4) the content should conform with any state or local syllabi that must be followed; (5) the statements must be accurate.[3] To these may be added a sixth point: (6) the content should reflect the unknowns and uncertainties in science as well as the knowns.

2. *Organization.* Two distinct types of organization are seen in secondary school science books.[4] In the type using logical organization, concepts and principles are developed in the way that a well educated person might organize them; this is the form usually seen in college texts and in high school physics and chemistry texts. In the type using psychological organization, the attempt is made to present the material in the order that would be most meaningful to pupils for whom it is designed; many general science and biology texts have been given this type of organization.

Books with a psychological organization may be differentiated according to the nature of the learning segments. Some books use environmental units; some use problem units.[5,6] Ideally, a textbook should agree with the organization used for the course of study. Otherwise it may be somewhat awkward to refer to readily.

3. *Literary style and vocabulary.* Literary style has much to do with the readability of a book. Although style is difficult to judge, some points to be looked for are: (1) length of sentences; (2) directness of sentences; (3) number of ideas per sentence; (4) use of lead sentences for paragraphs; (5) presence or absence of irrelevant thoughts; (6) continuity of thought.

Vocabulary lends itself to objective consideration and several studies have been carried out. Curtis summarized the results of ninety-nine investigations as follows:

[2] Miller, David F., and Blaydes, Glenn W., *Methods and Materials for Teaching Biological Sciences,* McGraw-Hill, New York, 1938.
[3] Mallinson, George G., "How to Use the Textbook in Science Teaching," *School Science and Mathematics,* November, 1953.
[4] Groins, William F., "Science Textbook Needs in High Schools," *The Science Teacher,* March, 1953.
[5] Hoff, Arthur G., *Secondary School Science Teaching,* Blakiston, Philadelphia, 1950.
[6] Heiss, Elwood, et al., *Modern Science Teaching,* Macmillan, New York, 1954.

pearance: artistry of cover, durability of binding, size of the book, quality of paper, length of line, and size and legibility of type.[9] The book should have an attractive over-all appearance. The cover design and the color of the binding should be attractive. The size of the book may have unsuspected psychological implications. If the book is poorly proportioned, too long and narrow or too short and thick, it will be unappealing. If the book is excessively large, its mere encyclopedic bulk is likely to make the student feel that it will be dull and difficult reading. During the past few decades, science textbooks have increased tremendously in size.[10] The trend today, however, is toward texts which are less encyclopedic and more functional in everyday life.[11]

The length of line and the size and legibility of type are important mechanical factors that determine the ease and comfort with which the text may be read. If the book is rather wide, the double-column page will probably be more attractive. Ample space should be left between lines to provide for ease in reading. The type should be sharp and printed on a good quality paper.

Factors of little importance in choosing a text. As previously mentioned, the educational rank and reputation of the author should not be one of the criteria used in evaluating the text. This should not be interpreted to mean that noted science educators do not usually write good books, but rather that a book should not be excluded from consideration merely because its author is not well known. It should be noted that the present trend is for teams of authors rather than a single author for science textbooks.[12] A team of authors, especially if it consists of experts on subject matter as well as experts on the psychology of education, often produce a better text than could a single author.

The Thirtieth Yearbook of the National Society for the Study of Education lists some of the factors which should not be considered in selecting a textbook.[13] The prestige of the publisher should not be considered. The yearbook points out that wide use of a text is not necessarily a good criterion for selecting a textbook. Even though it may serve well in many schools, it may not satisfy the needs of an in-

[9] Hunter, George W., *Science Teaching*, American Book, New York, 1934.
[10] St. Lawrence, Francis, "Are Heavy Textbooks Necessary?" *Science Teacher*, March, 1951.
[11] Nelson, V. R., and Brown, S. B., "Perceptible Changes in Science Education—1954," *School Science and Mathematics*, December, 1954.
[12] *Ibid.*
[13] *The Textbook in American Education*, Part II, Thirtieth Yearbook of the National Society for the Study of Education, University of Chicago Press, Chicago, 1931.

dividual school. The cost, although it must of necessity be considered, should not be overemphasized in selecting a textbook. A cheap textbook which proves unsatisfactory and must be discarded after a very short period of use actually costs more in the long run than a more expensive book that can be used for many years.

The score-card method of evaluating textbooks. Various score cards and check lists have been devised to make the selection of textbooks as objective as possible. All the major factors considered important in evaluating textbooks are listed and assigned a certain number of points to establish the relative weight of each. Sometimes the major items are broken into specifics, each with its own point value. After a textbook has been rated according to this list, its total score may be compared with that of other textbooks.

One example of a score card for textbook evaluation is the following:

	Points
1. Educational rank of author	50
2. Mechanical make-up and cost	100
3. Psychological soundness	300
4. Subject matter	250
5. Literary style	110
6. Learning exercises	140
7. Teacher's helps	50
Total	1000 [14]

Another kind of score card, designed to speed up the process of evaluation, is the "spot check" method, illustrated by *Vogel's Spot Check Evaluation Scale* [15] (pages 232-233). On this score card, each item has been assigned a maximum value of two points.

Obviously the use of a score card is not truly objective, because each separate item is judged subjectively. It does have the advantage of systematically directing the evaluator's attention to each of the factors considered important. Some degree of objectivity is introduced in the totaling of the points.

The danger in the use of score cards comes with the attempts to compare books by their scores. Some important points may have been ignored in constructing the card; others are too intangible to be defined. The only real test of whether a textbook will serve satisfactorily in the classroom is actual use.

[14] Hunter, George W., *Science Teaching*, American Book, New York, 1934.
[15] Vogel, Louis F., "A Spot Check Evaluation Scale for High School Science Textbooks," *The Science Teacher*, March, 1951.

SCIENCE NOTEBOOKS

The science notebook is a valuable teaching device, suitable for a wide range of interests and abilities. At its best, it is a place to keep records, a summarization of learnings, an exercise in organization, a medium for self-expression, an indication of progress, and an accomplishment in which to take pride.

That notebooks seem at times to have little or no value, that they are commonly viewed with distaste by teachers and pupils alike, is not the fault of the notebooks. Any teaching device improperly used may be of more harm than good.

Functions of the science notebook. By tradition, the chief function of a *notebook is to keep records. In it are to be kept records of* experiments and of observations in field and classroom. Notes made of presentations by the teacher or by pupils, of assigned and voluntary readings, and of films and slides find a logical niche in the science notebook. The notebook is also a satisfactory place to keep duplicated material given out by the teacher, corrected test papers, assigned book reports, and other papers.

The task of keeping this material in order gives the pupils many opportunities to organize their learnings. As they prepare summary sheets for each unit and a table of contents for the entire notebook, they see the development of the program, topic by topic, unit by unit.

The notebook is a device for review. As pupils keep the material up to date and in proper order they constantly review the work they have done. Before tests, they find in the notebook the material on which they are to be tested.

According to more modern usage, the notebook may be a medium for self-expression. For supplementation of assigned work, a pupil may write in the notebook original stories, essays, poems and playlets. He may make diagrams, sketches, cartoons, and paintings as his particular interests and talents dictate. He may enjoy pasting in clippings, a form of self-expression favored by many pupils.

Finally, the science notebook may become tangible evidence of progress. As the notebook thickens, topic by topic, and unit by unit, pupils recognize that their learnings are growing too. The final notebook or any one of its sections may be a project in which a pupil takes great pride, winning with it the approval of his fellows and the commendations of his teacher. And the quality of the contents of a notebook give the teacher another measure of the interest, efforts, and achievements of its maker.

VOGEL'S SPOT CHECK TEXTBOOK EVALUATION SCALE

Textbook ______________________________

Author ______________________________

Publisher ______________________________

Copyright year ________________

List price ________________

Score ________________

I. *Qualification of author* (see title page, preface to textbook and preface to teacher's manual)

(2) The author has taught the subject about which he is writing.

(2) The author holds advanced degrees in related fields.

(2) The author has received assistance from specialists in preparing his manuscript.

(2) The author has tried out his material in classroom situations.

(2) The author's point of view, theory, or philosophy is in harmony with that of my school.

Partial score ________________

II. *Organization* (see table of contents, the preface, the section headings through one unit, and the end of one chapter)

(2) There is a central theme which correlates the whole textbook.

(2) The textbook is organized into units which are based on student interest and probability of use in everyday life.

(2) The organization makes use of topics already taught in my school.

(2) Questions and/or problems at the end of chapters are graded explicitly in difficulty.

Partial score ________________

III. *Content* (see table of contents, index, and five *text pages*)

(2) The textbook contains all of the topics necessary for my course.

(2) Material from one part of the textbook is cross-referenced with similar material in another part of the book.

(2) The historical development of science is *given some place.*

(2) Topics dealing with the latest advances of science, such as atomic energy, are included.

(2) The social significance of science is stressed.

Partial score ________________

IV. *Presentation of material* (see any five *introductions to chapters,* or problems)

(2) The inductive approach is used wherever possible in introducing a new topic.

(2) The problem-solving aspect of scientific method is stressed.

(2) The author's style is informal and interesting.

(2) Unfamiliar scientific terms are set in italics or boldface.

(2) Important principles are set in italics or boldface.

Partial score ________________

V. *Accuracy* (select any five topics in the index and look them up in the text)

(2) All the items I looked up are on the pages indicated in the index.

(2) The items I looked up are scientifically correct.
(2) Teleological expressions are avoided.
(2) Personification is avoided.
(2) No ambiguity is apparent.

Partial score ______________

VI. *Readability* (see any one text page)
(2) The average number of words per sentence is below 21.
(2) Sixty percent of the sentences are simple or compound, as opposed to complex.
(2) There are at least four personal references per 100 words.
(2) There is at least one application for each abstract principle.
(2) There are not more than 42 affixes per 100 words.

Partial score ______________

VII. *Adaptability* (see table of contents and any five text pages)
(2) The textbook is satisfactory for slow, average, and brilliant students.
(2) Students with rural and city background will find the text useful.
(2) The textbook is arranged so that certain sections can readily be omitted.
(2) The authors treat controversial subjects impartially.
(2) In general the text fits my particular community needs.

Partial score ______________

VIII. *Teaching aids* (see end of chapters, appendix, and teacher's manual)
(2) Summaries, questions, and problems at the ends of chapters are adequate.
(2) References for teachers and students are annotated.
(2) Appendix material is pertinent and useful.
(2) The teacher's manual is more than an answer book.
(2) An annotated up-to-date film list is provided.

Partial score ______________

IX. *Illustrations* (see any 10 illustrations)
(2) The illustrations are relatively modern.
(2) The photographic reproductions are large and clear.
(2) The line cuts are well drawn and adequately labeled.
(2) The figures are tied into the textual material by direct reference.
(2) The legends under the illustrations are useful learning devices.

Partial score ______________

X. *Appearance* (see cover and leaf through the text)
(2) The appearance of the cover is attractive.
(2) The size and shape of the textbook would not be a handicap to students.
(2) The placement of the illustrations is pleasing.
(2) The design of most pages is open, rather than crowded.
(2) The size of the type makes for easy reading.

Partial score ______________

A science notebook may not be all these things to all pupils. Some brilliant pupils are understandably impatient with the routine of keeping a notebook. Some academically retarded pupils may find no satisfaction in any of the activities involved. All pupils react differently to notebooks. For this reason, notebook requirements must be as flexible as everything else in the science program.

Providing for notebook work. It is well to specify at the beginning of a program the exact form of the notebook that will be used. Left to themselves, pupils bring in a variety of shapes, sizes and types. Some of these notebooks are difficult to adapt to the requirements of a good notebook program.

A loose-leaf notebook is essential for the addition of new material from time to time and for the occasional reorganization of the old material. Spiral notebooks and composition books permit no flexibility; materials must be left in the order in which they are entered.

The standard notebook size, 8½ inches by 11 inches, is convenient for the addition of any duplicated sheets provided by the teacher, which are usually of this size. Duplicated materials added to smaller notebooks must be folded and make awkward inclusions.

The exact number of rings in the notebook is not critical but all notebooks should be the same. Then duplicated materials may be punched before being given out. Pupils need both lined and unlined paper. The lined paper is best for longhand writing. .Unlined paper is best for drawings and for clippings. It is also well for pupils to buy gummed ring reinforcements for the pages of their notebooks. Outer pages are easily torn out and lost without some form of protection where the rings pass through the holes.

A pupil may produce far more than enough material to fill a standard notebook during the course of a year. Some teachers require the purchase of manila covers, one for each unit, as well as a standard cover. At the end of each unit a pupil removes the material from his notebook and puts it in one of the manila covers, securing the pages with rings or paper fasteners. The cover may be decorated with designs appropriate to the unit. Thus at the end of the year, a pupil has the equivalent of several notebooks, one for each unit and each in its own cover.

There are psychological advantages to such a division of notebook materials. For each unit a pupil starts afresh. If he has taken pride in one section he is encouraged to do equally well on the next. If he has been careless on one unit, his failures are no longer visible to haunt him and interfere with the pride he might take in his work on the next unit.

A few materials kept on hand in the classroom are helpful in en-

couraging notebook work. A small supply of lined and unlined paper and some gummed ring reinforcements are needed for pupils who use up their own supply or forget to bring enough. A pile of old magazines, several pairs of scissors, and a plentiful supply of paste provide pupils with clippings for their notebooks. Colored pencils and crayons enable pupils to add color to their drawings. And if possible, a teacher should provide a paper punch to make holes in the specified covers and in the inserted material.

The basic notebook. Adolescents being what they are, few of them undertake notebooks voluntarily. A teacher must provide the initial impetus by requiring a certain minimum amount of work. As the unit progresses he may offer numerous suggestions for supplementing the required work, and he may occasionally provide time for such optional work.

The teacher outlines the minimum content of the notebooks as he makes his unit plans. Most of the required material is closely associated with the basic activities he expects all pupils to carry out. He may require records of assigned experiments, planned demonstrations, and general field work. He may require short written explanations of devices or phenomena considered by the class as a whole. In addition, he may demand a table of contents and a concluding summary of learnings.

The basic notebook should be made as interesting as possible. It should never represent drudgery. Too often pupils come to hate notebook work because they are forced to do endless copying of trivial and useless material. Much record keeping can be made interesting through varying the procedures. Commonly demonstrations are best recorded by diagrams supplemented by labels and captions. Tables and graphs are often the most effective ways for recording data obtained from experiments and field observations.

The teacher may dictate the form of the records used in the basic notebook. Or he may permit the class to work out the form to be adopted for a specific experiment or field study. The teacher may give out duplicated sheets on which there are diagrams to label, tables to fill in, or squared sections for graph making. On occasion, when a certain point seems especially important, the teacher may dictate or write an explanation on the blackboard for pupils to copy, or give out the statement on duplicated sheets. More worthwhile, if uniformity of expression and thinking is desired, he may permit the class to formulate the statements to be copied into the notebooks.

Generally, class time is used for work on the basic notebook. At the conclusion of a demonstration or experiment, or after a discussion,

pupils are given several minutes to make the required drawings and write out their observations, conclusions and explanations.

Some teachers make extensive use of work sheets. These are similar to pages found in workbooks. They contain directions for activities, blanks to be filled in, spaces for diagrams or diagrams to be labeled, and questions to be answered. These work sheets are useful for general assignments, although their use may be overdone. The finished work sheets should become part of the notebooks.

Pupils may be asked to carry out certain uniform assignments at home or in study hall. These may be based on prepared question sheets, on textbook readings or questions, or on library assignments. The teacher may permit flexibility in the basic notebook. He may prepare a list of possible assignments and permit pupils to choose from the list.

For the unit summary, the teacher may dictate an outline or provide one on duplicated sheets. For greater value, the pupils may develop their own outline, discussing their learnings, organizing them, and dictating the form in which the points are to appear. The final outline may be written on the blackboard for pupils to copy in their notebooks, or it may be duplicated for distribution. To aid in review a teacher may present a list of questions to be answered or he may assign certain questions at the ends of textbook chapters. Pupils are expected to write the answers in their notebooks.

The amount of material to be included in the basic notebook must be decided upon by each individual teacher. It is a matter of personal viewpoint. However, it may be said that many teachers have a tendency to require too much, leaving little pupil time or enthusiasm for following up individual interests. Teachers whose pupils do much optional notebook work rarely make uniform notebook assignments more than once or twice a week.

Once assignments have been made, pupils should be held accountable for their completion. Because class time is provided, few pupils have difficulty finishing the assigned work but there are always some who cannot use their time efficiently. Occasional check-ups on these pupils keep them from falling so far behind they develop a distaste for notebook work. It is also well to set aside a part of a period the day before a notebook is due to check required work against a list presented by the teacher. Pupils then use the remaining time to bring the required work to completion if necessary, or to do optional work if required work has been done.

Supplementing the basic notebook. The basic notebook, made up of a minimum number of required assignments as just described, is a

framework upon which pupils may build as they wish. Many pupils find great satisfaction in notebook activities and display enthusiasm and initiative in their work. Other pupils develop little interest in their notebooks. Some have difficulty in completing minimum assignments. A teacher should recognize these differences in individuals and not expect high quality work from each. On the other hand he can always try to encourage increased efforts in hopes that his pupils will discover and take pride in unsuspected talents.

Optional work is stimulated by providing time early in each unit.

Each year, as Mr. Watson's seventh grade began the study of "Water In Our Lives," Mr. Watson set aside half of the fourth or fifth lesson for notebook work. He brought into the classroom a pile of popular magazines, scissors, and paste. He asked the pupils to find pictures of the uses of water to clip and put in their notebooks.

At the end of the period, after materials had been put away, Mr. Watson explained that pupils could look at home for more clippings to be added to the notebooks. He also mentioned that pupils could make drawings or paintings and asked for suggestions of subjects. Few pupils ever failed to respond to this approach. Many added dozens of clippings to their notebooks. Some copied diagrams from texts and encyclopedias. Others made colored drawings.

This same technique of starting all pupils on a specific activity may be used in other ways.

During a unit on astronomy, Mr. Watson asked his eighth grade pupils to make cartoons showing conditions encountered by the first men to land on the moon. Each pupil made at least one cartoon, but many made whole sections of cartoons and some used cartoons when doing notebook work for other units.

Color has strong appeal. Many pupils who take little interest in a black and white notebook become enthusiastic about the same type of work when color is added.

As his seventh grade pupils made their first notebook diagrams of the year, Mr. Watson would walk about the room giving praise and encouragement. Finally he would select one pupil and suggest that he use a red pencil to make arrows more promient.

Once this diagram was completed, he would ask the pupil to display it to the class. Other pupils invariably wanted to use colored pencils too and from then on their notebooks became much more colorful.

Title pages permit pupils to exercise a certain amount of individuality.

Near the close of each unit, Miss Thompson gave her pupils time to prepare a title page for the notebook work on the unit. She never dictated the form of the page but she did suggest that the decorations be in keeping with the content of the unit.

Many novel and interesting motifs were worked out and displayed to the class. Sometimes pupils who had previously shown little interest in their notebooks became interested in adding more material to maintain the standard established.

Pupils are sometimes stimulated by seeing what other pupils have done.

At the end of each unit, Miss Harrington customarily chose the two best notebooks from each of her five sections. She put these on display and allowed pupils to look at them during class time. Thus the pupils who had made the notebooks received recognition and others benefited by the content and by the suggestions for material to be included.

Types of optional work that pupils may be encouraged to put in their notebooks include:

1. Decorated covers
2. Decorated title pages
3. Expansions of assigned work
4. Reports of optional experiments
5. Reports of optional field observations
6. Reports of problems worked out at home
7. Clippings of pictures and articles
8. Drawings and paintings
9. Cartoons
10. Original poems and stories
11. Clippings of poems and stories
12. Diagrams made from actual observations
13. Diagrams copied from books
14. Lists of applications or other items
15. Book and film reviews

Giving recognition for notebook work. Mention has already been made of one teacher's method of recognizing superior notebook work by selecting and displaying the two best notebooks from each section. A number of other techniques may be used. The teacher may write favorable comments in the margins and commend pupils in private conversation. The teacher may call attention to excellent sections of notebooks during class time, reading selections or asking the pupils who prepared them to read selections. Materials that lend themselves to display may be made the subject of bulletin board exhibits. An unusual notebook may be partly separated and displayed in a show case.

There is a natural tendency to reward quantity instead of quality. A teacher should form the habit of looking for original work, for unusual activities, and for careful organization. Public commendation for these qualities encourages other pupils to follow the same pattern and to some extent explains to pupils who have spent hours gathering unrelated materials why they have not been selected for special attention.

Grades for notebooks represent part of the reward given for special effort. All notebooks should be graded. However, the teacher should remember that notebook work is not a goal of science education. Rather it is a means by which pupils can be helped to develop themselves. Some pupils benefit greatly from notebook work; others, little.

The basic notebook material may be graded in terms of completeness, neatness, and conformity to the pattern of organization. It cannot be graded on quality because this has been determined by the teacher. All pupils should receive a grade on this material. Optional material may well be graded separately. Or optional material may be used to increase the grade given for the basic notebook. Pupils should be given some understanding of the standards used in grading this material.

SCIENCE WORKBOOKS

Workbooks are categorically condemned by many leaders in education, but sales continue to mount. Their popularity is certainly due less to high teaching value than to convenience. On the other hand, blanket condemnation is not entirely deserved; workbooks do have certain assets upon which teachers can capitalize.

Workbooks vary greatly in content and organization. At one extreme are workbooks that reprint pages of associated textbooks, replacing key words with blanks that are to be filled in by pupils after reading their texts. These are the workbooks that have given the species a bad name. Their only function is to keep pupils busy; the harm they do in disgusting pupils with science cannot be estimated.

At the other extreme are workbooks that make provision for many different types of activities—forms for reporting data, diagrams to be labeled, blank spaces for sketches and clippings, suggestions for supplementary work, study guides for reading assignments, and self-testing devices. Sometimes in addition the teacher is provided with pads of tests, one per pupil, to be used in evaluating pupil achievement.

Workbooks of the latter type serve as a combined course of study, a study guide, and a record book. As a course of study it shows the pupil where he has been and where he is going; as a study guide it

gives him detailed instructions for his work; as a record book it gives him a convenient depository for his findings.

Heavily burdened teachers find the better workbooks useful in conserving time and energy. They are freed from the preparation of study outlines, work sheets and laboratory directions. They do not need to devise so many review and drill exercises. They find the standardized records easy to check. They are relieved of part of the burden of evaluation. The beginning teacher and the inadequately prepared teacher also find workbooks of value. They gain the security that comes from knowing exactly what to do next and from realizing that the pupils have been given adequate directions.

Workbooks help pupils who are working under self-direction to study more effectively. Pupils who have missed time because of illness or from having left school prematurely can make up work without close supervision.

For all their advantages, the limitations of workbooks must not be forgotten. Workbooks are relatively inflexible; the content is highly organized and cannot be altered easily. There is little or no provision for the inclusion of new materials. Unused sections offend both the pupils and the parents who buy the books. Workbooks are directed toward uniform outcomes; if they dominate the program, pupils have little opportunity to develop special interests and talents. Most serious of all, workbooks deny pupils any participation in the planning process, any incentive to do independent work, any practice in formulating their own problems and any encouragement to do their own thinking.

It is far too easy for workbooks to dominate the program. The following lesson was observed during a search for master teachers under whom to place cadet teachers.

Mr. Andrews brought his general science class to order and directed them to open their workbooks to page 92. He asked the pupils to read in turn the answers to the questions that they were supposed to have done as a homework assignment. Upon the completion of this activity Mr. Andrews assigned pages 95 and 96. For the next twenty minutes he sat at his desk while the pupils looked up the answers to the questions on these pages, each of which was keyed to the textbook. The last ten minutes of the period was spent in checking the answers. The assignment was to work on another three pages of the workbook.

There are situations in which the use of workbooks is justified but they should always be used with care. If they come to dominate the program they operate contrary to the major objectives of science education. Teachers who feel they must use them should work toward the day when they are completely free of them.

Suggested activities

1. Review several science textbooks, making note of the special features that are provided by each. Apply the Vogel spot check test to one of these.

2. Read a general science textbook completely. Apply one of the standard reading formulas to randomly selected portions of it to judge its reading level.

3. Prepare an assignment sheet to help retarded readers use their textbook more effectively.

4. Plan a fifteen-minute review based on the pictures in a text book unit.

5. Review several science workbooks and decide what is the value of each and under what circumstances it can be used effectively.

6. Plan one unit of a basic notebook which would be required of each pupil in a class. Also list suggestions for optional materials pupils might include.

Suggested readings

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LANGUAGE AS A TEACHING AID

chapter 10

A prodigious number of words, both oral and written, are used during the course of a single lesson. Printed, the words would often fill a small book. Most of the words are used orally with some lessons based wholly or in large part upon classroom conversation. Speech is unquestionably the most extensively used of all teaching devices.

Perhaps because speech is such a natural process, teachers do not always give adequate thought to it when making their plans. All too often their lessons degenerate into rambling and uninspired discourses that hold the attention of but few pupils. It can be noted that most of the discipline problems of beginning teachers arise during such inadequately planned periods. Good planning is required for the use of language, just as for all other teaching aids. Used with purpose, language meets a number of needs in the classroom. The specific advantages of words must be understood and utilized properly. Their limitations must be realized and compensated for.

Other chapters of this book will also deal with the wise use of language—reading, pupil reports, and testing. This chapter will deal chiefly with the way a science teacher uses words in the classroom as part of his regular presentations.

TEACHER PRESENTATIONS

The Scoutmaster's Handbook of the Boy Scouts of America recommends that scoutmasters confine their remarks during scout meetings

to a brief period called the "Scoutmaster's Three Minutes." This is sound advice for scoutmasters and is worthy of consideration by science teachers as well. Few individuals have the ability to hold an audience through the power of words alone. Not many science teachers can be included among the ranks of the fortunate. Strictly oral presentations in the classroom might well be limited to the "Science Teacher's Three Minutes."

Giving directions for classroom activities. The quality of the instructions given for general class activities determines in part the effectiveness of the activities. Clear-cut and business-like instruction inspires respect. Knowing exactly what to do and what to look for, pupils are able to set to work immediately with assurance. Carelessly presented directions, on the other hand, tend to result in confusion. Pupils fumble, look about to see what others are doing, distract each other with whispers, annoy the teacher with questions, and use their uncertainties as an excuse for dallying. Serious discipline problems sometimes arise.

Mr. Langerford, student teacher in the seventh grade, directed his pupils to read pages 67 and 68 in the text book. A few pupils began reading immediately. Most of the others had forgotten the assignment by the time they had located their books. These last began asking the page numbers of each other, at first in whispers, then in undertones.

At the same time several hands were up. Mr. Langerford began answering the questions one by one.

"What is it, Martha?"

"Did you say page 67 or 68?"

"Both pages, Martha. What do you want, Tom?"

"What pages did you say, Mr. Langerford?"

"Pages 67 and 68, both. Yes, George."

"What pages are we supposed to read?"

Mr. Langerford's voice became tinged with irritation. "I just told you three times. Don't you ever listen? Pages 67 and 68!"

George's face reddened and several pupils tittered. Joe, whose book was open, closed it conspicuously and asked in an innocent tone but with a smirk on his face, "What pages did you say, Mr. Langerford?"

Experienced teachers avoid these situations. One teacher might direct his pupils to take out their textbooks and only after the books were ready would he give the page assignment. Another might write the page numbers on the blackboard and then make the assignment, referring to these numbers as he does so.

Strictly oral directions are satisfactory only for the simplest of activities. Few people can keep in mind a lengthy set of directions

after one hearing. Pupils need specific help in visualizing the procedures they are to follow—printed directions, diagrams, charts and other types of visual aids.

When two or more steps are involved, procedures may be written on the blackboard or printed on sheets to be given to each pupil. The directions may be drawn up by the teacher alone or they may be prepared by the pupils.

A senior science class decided that each member should have practice in removing stains from clothing. First they listed the common types of stains. Then they divided into committees, each of which would investigate one type of stain, prepare directions for its removal, and set up an experiment in which the others could participate. Two girls volunteered to type up the directions for duplication.

Visual aids are always useful for giving directions. A map helps pupils locate an item to be studied or defines the area in which a field study is to be confined. A diagram illustrates an electrical circuit to be wired. A photograph or slide shows what the final product of a construction activity should look like.

The best visual aids are the actual materials that are to be used in the activity itself.

Mr. Ries provided his biology pupils with printed sheets that gave directions for pressing and mounting the plants they were to collect for study. Then he gave a demonstration, following the steps printed on the sheets, and using plants which he had collected to illustrate some of the problems the pupils might encounter.

The lecture method. Lectures seem to have certain immediate advantages. A large amount of material can be covered in a single class period. Time needed for troublesome laboratory and field activities is reduced. Fewer books and other teaching materials must be provided.

The advantages seem so obvious that lecturing has always had strong influence on teaching method. The extreme is reached in those university courses that are based entirely upon the lecture method. All that students need do is listen quietly, take notes, and assimilate the information that the instructor has gathered so diligently and organized so logically.

Unfortunately, the learning process is not so simple. The "pouring in" method is educationally unsound and cannot be recommended for the secondary school. Adolescents are too restless, too preoccupied with immediate problems, and too concerned with recognition by their fellows for purely passive learning. They are handicapped by the

limitations of oral communication—inadequate vocabularies and insufficient experience backgrounds. They need meaningful experiences, active procedures, and self-identification with each new situation.

Teachers should limit themselves to brief presentations, such as a short description of a process, a statement of fact, a narration of personal experience.

Mr. Bradshaw, who had been stationed on a Caribbean island as a meteorologist during his military service, was finding weather a difficult subject to teach to a class of eighth graders. Pupils had little enthusiasm for the topic. Then one day Mr. Bradshaw happened to say, "Once I saw what a hurricane can do. I was on an island in the Caribbean—" Almost immediately the class attitude reversed itself.

Thus Mr. Bradshaw discovered by accident the most valuable function of the oral presentation—the development of a vicarious experience. Mr. Bradshaw's pupils were able to share with him in imagination his experiences with a hurricane. They then had a background that enabled them to communicate with him. A teacher will find that his most effective oral presentations deal with his own experiences. He is able to supply the detail that makes the images vivid in the minds of his listeners.

Any oral presentation is effective only to the degree with which satisfactory images are evoked. That is why slides, exhibits and demonstration materials are so helpful to a speaker. They help to make up for the limitations of words. Teachers should use them extensively during any of their oral presentations.

Guest speakers. Guest speakers contribute new points of view to the science program. They can answer questions with the authority of their experiences. They can supply details that are unavailable from the usual classroom resources. Potential guest speakers exist everywhere. It is only necessary that an individual have had experiences in some field of science to be able to make contributions. A school janitor can talk about the school heating system. A nurse can describe aseptic procedures in a hospital. A parent can talk about his experiences flying an airplane. A pupil from another room can talk about model airplane engines.

It must be remembered that individuals vary greatly in their ability to interest the adolescent audience. The most interesting speakers usually tell about their own experiences. It is sometimes desirable to encourage all speakers to do so.

Mr. Pierce, the fire marshal, had obviously prepared diligently for his talk on fire prevention to the combined eighth grades of the local junior high

school. But the mass of statistics he was presenting interested his audience very little. The pupils were becoming increasingly restless and were almost at the stage of rudeness.

The principal, Mr. Bowan, sharing the platform with Mr. Pierce, recognized the nature of the problem. At the first opportunity, when Mr. Pierce had turned to him at the end of making a point, he gestured with his hand to arrest Mr. Pierce's attention.

"Mr Pierce," he said, "I'd like to know about some of the dangerous conditions you have seen as you make your inspections. I think these boys and girls would like to know about them too."

The question launched Mr. Pierce upon a description of some of the places he had visited and some of the fires he had investigated. His audience became alert at once. At the end of his talk a number of the pupils asked questions and some stayed to talk with him after the class bell rang.

Whenever possible guest speakers should be encouraged to supplement their talks with slides, exhibits and demonstration materials. In

It is often better to take pupils to a place where an expert can demonstrate his points with actual materials than to invite the expert to give a completely verbal presentation in the classroom. Few individuals have the power to hold an adolescent audience with words alone.

some instances it is wise to take the class to the speaker rather than the reverse if by so doing the speaker will have better facilities for illustrating the points he intends to make.

Mr. Morris had asked Mr. Detling to speak to his physics class about making a reflecting telescope, since Mr. Detling had made a couple of his own. After thinking the matter over he asked Mr. Detling if it might not be better to take the class to Mr. Detling's home where the pupils could see the materials which were used. Mr. Detling agreed and was able to give both the practice and the theory of telescope making.

When extending an invitation to a guest speaker it is usually wise to make a specific request unless the speaker is known to be interesting to adolescent audiences. He may be asked to describe his experiences in a particular situation or to explain the operation of some well known device. He may also be asked to limit his talk to fifteen minutes to provide time for questions. Inexperienced speakers are usually grateful for such guidance.

QUESTION-ANSWER TECHNIQUES

Teachers use oral questions much more than they probably realize. It is not unusual for a teacher to spend more than half a period in interrogation. Certainly questioning has a place in the science program but it is doubtful whether the allocation of so much time to one type of activity can be justified. Teachers should give serious consideration to the amount and type of questioning they use.

Some functions of oral questioning. Oral questioning helps establish something of the experience backgrounds of the pupils and is especially useful at the beginning of each new topic. "Who has travelled in an airplane?" "Who has watched a pilot control an airplane?" "Who has seen an airplane take off?" "Who has seen an airplane land?"

Such questions represent a form of pre-testing and will be referred to again in the chapter on Tests and Testing. The answers suggest the extent of the foundation upon which teachers can build. If this information is especially critical, it may be well to phrase each question in both the positive and negative sense in order to determine which pupils lack experiences as well as those who have had them: "Who has watched a pilot control an airplane?" "Who has never had a chance to see a pilot control an airplane?"

Oral questioning can be used to help pupils recall past experiences that may be utilized during the progress of a unit.

Mr Bernstein held up a fifteen-ampere fuse and asked his seventh grade, "Does anyone know what this is?"

Several hands went up. "It's a fuse," said one boy.

"That's right," said Mr. Bernstein. "How many of you have heard of electric fuses before?"

All hands were raised.

"How many of you have seen electric fuses in your home?"

About half the hands went up. Three pupils described where electric fuses were located in their homes.

"Who knows what they do?"

Several pupils were eager to talk. One girl told of the occasion she plugged in an electric toaster and caused a frightening spark and the extinguishing of the lights in the kitchen. Another told of the time all the lights in the lower rooms of the house were out until an electrician could come to replace the fuses.

Through his questioning Mr. Bernstein set the stage for a study of electric fuses. The pupils knew what a fuse looks like and they had some concept of its importance. Pupils who had seen fuses before or who had had experiences with them were now thinking in terms of these experiences. Others had gained vicarious experiences with fuses through the narrations of their classmates. They all sensed the desirability for knowing more about them.

Oral questions are valuable instruments for review and drill but care should be taken not to overuse them in this capacity. Too few pupils can participate actively, and too many pupils are forced to sit quietly by. After a few minutes of brisk questioning the activity should be ended in favor of a different one.

Oral questioning is not recommended for evaluation when the questioning is done in class. At best, each pupil can be asked only two or three questions. It is difficult to formulate a large number of questions of equal weight and some pupils may benefit from the responses of others. Injustices are almost certain to occur. However, when individual conferences are possible, oral questioning gives an excellent method for assessing pupil achievement. This method of evaluation will be discussed in the next chapter.

The fallacy of leading questions. "Leading questions" are much used to guide what are called "discussions." Typically the teacher asks a question which sets the pupils guessing. If an answer acceptable to the teacher is suggested a new topic is introduced. If no acceptable answer is given, the teacher asks related questions the answers to which lead step by step to the answer of the first question.

Mr. Milo's plans called for a discussion of conditions on the moon. Pupils had mentioned the lack of air, plants and water.

"Why do you suppose there's no water?" Mr. Milo asked.

Several moments of silence. Then a girl asked somewhat hesitatingly, "Is it because the sun is so hot it dries out the water?"

Mr. Milo's face became blank. "No," he said shortly. "Doesn't anyone else have an idea?"

The silence continued.

"Well," he asked, "What do you know about the size of the moon?"

"It's smaller than the earth," several pupils shouted.

"That's right. Now doesn't that help you?"

Silence resumed.

"Well, what keeps the water on the earth?"

A few moments more of silence broken at last by one of the boys, "I guess it doesn't have any other place to go."

"Of course it does!" Mr. Milo exclaimed impatiently. "It could go off into space." Then with a more hopeful expression, "What keeps you on the earth?"

"Gravity!" shouted several pupils in evident relief.

Mr. Milo's vigorous nod was accompanied by a pleased smile. "Good! Now how about the water on the moon?"

After a short silence one of the boys asked, "Isn't there gravity on the moon, too?"

"Yes, of course, but how does it compare with gravity on the earth?"

Silence.

"Think back. How about the size of the moon?"

Then a hand waved violently.

"Yes, Jim."

"There's less gravity on the moon. So the water flies off into space."

Mr. Milo beamed with pleasure. "That's very good thinking, Jim."

The above technique of teaching can be likened to such games as "beast, bird, or fish" or "Twenty Questions," except that it is not frankly labeled a guessing game. Indeed, because the questions of the teacher are finally answered, the pupils assume that they have been thinking and the teacher assumes that he has been teaching.

Formulating oral questions. Simplicity and directness are essential qualities of oral questions. Pupils have no opportunity to puzzle out the meanings of awkward and complex questions as they might were they reading them. They must grasp them immediately or not at all.

The pupils must be familiar with all the words used. The presence of one strange word, such as *superfluous* or *excessive*, distracts them and they lose the sense of the remaining words. Science teachers are

especially apt to forget the vocabulary limitations of boys and girls. Teachers are used to hearing and using words that are unfamiliar to the bulk of the population. Without thinking they often penalize a large number of their pupils by what is in effect excluding them from participation in the work of the class.

Commonplace words can often be substituted for unfamiliar words, sometimes to the general improvement of the question:

Original: What happens to the superfluous water in a leaf?
Improved: What happens to the unused water in a leaf?
Original: Why does a bottle of warm soda pop effervesce when opened?
Improved: Why does a bottle of warm soda pop foam when it is opened?

There are often good substitutes for technical words. Unless the technical word itself is considered important, it is usually well to make the substitution.

Original: As your epidermis is worn away, how is it replaced?
Improved. As your outer layer of skin is worn away, how is it replaced?
Original: In what direction is light refracted as it passes from air to water?
Improved: In what direction is light bent as it passes from air to water?

When a concept is being tested and the knowledge of a word is considered essential in answering the question, there are in effect two things being tested with the same question. The question may well be divided to test each idea separately.

Original: Where is the cambium layer in a tree trunk?
Improved: Where is the growing region of a tree trunk?
What is the growing region called?
or
What is the growing region of a tree trunk called?
Where is the cambium layer in a tree trunk?

Technical jargon should be avoided unless there is good reason for using it.

Original: How can we measure the pH of the soil?
Improved: How can we determine the acidity of the soil?

Questions with inverted structure and dangling clauses should be avoided in favor of direct questions.

Original: When more salt is added to a salt solution, what happens to the freezing temperature?
Improved: What happens to the freezing temperature of a salt solution as more salt is added?

Original: If an air mass passes across the Great Lakes, what are its characteristics in winter?
Improved: What are the characteristics of an air mass that passes across the Great Lakes in winter?

Hypothetical questions can become so involved as the teacher tries to think of every eventuality that few pupils can follow them. The more complex questions should be written out rather than given orally.

Example: Suppose you owned a wood lot and you didn't cut any trees for fifty years and you didn't let cows graze in it, and there were no forest fires, what would the trees be like?

Sometimes teachers think in terms of completion-type questions and use them in oral questioning. Pupils have considerable difficulty in visualizing the questions.

Original: Pollen is borne on the what?
Improved: On what part of the flower is pollen borne?
Original: The best way to make wood catch fire rapidly is blank.
Improved: What can you do to wood to make it catch fire rapidly?
Original: Quartz crystals are formed from the what dissolved in ground water?
Improved: What is there dissolved in ground water that crystallizes to make quartz?

Questions that can be answered by yes or no, or by any other either-or combination, require little or no thinking. If the first guess is not correct the second must be correct. Such questions have little value.

Original: Does a fish give off carbon dioxide?
Improved: What gas does a fish give off during respiration?

Controlling question-answer situations. Insistence upon a few minor formalities can do much to maintain order during question-answer sessions. Even those experienced teachers who seem to permit the utmost freedom in their classrooms demand respect while they are asking questions and listening to answers. Beginning teachers, who may not recognize the importance of the formalities, sometimes let the situation deteriorate.

Pupils should learn that permission is needed for contributing an answer. Teachers should be consistent in acknowledging only those who request permission to speak. The usual signal asking permission to speak is the raised hand. Teachers should always give this signal preference. If one pupil raises his hand and a second gives an answer without permission, the former should be recognized and the latter should be ignored no matter whether his answer is wrong or right.

Commonly several hands are raised at the same time. Usually it is best to give the pupil whose hand went up first the privilege of answering but the other pupils should be told why that particular selection was made. If two or more hands are raised simultaneously, one pupil may be selected arbitrarily with the other ones being acknowledged.

"I can see that both John and Mary are ready to answer my question. I'll let John answer this one."

In most classes there are a few pupils who tend to dominate question-answer sessions. They should not be ignored as long as they raise their hands because they are cooperating completely with the teacher. And yet a teacher usually wishes to bring other pupils into the picture. Tact is needed.

"John, I see that you know the answer to this question, too. Let's ask June to answer it and then you tell me if you agree with her."

To bring a non-participating pupil into the picture, the teacher may ask special questions that the pupil's background enables him to answer better than anyone else. This technique counteracts his feeling of isolation and helps him become a member of the group.

A question directed specifically to a pupil whose mind is obviously wandering will recall him to the activity at hand. This may prevent him from becoming engaged in some other activity that will disturb others in the class.

Incorrect answers should be treated with the same courtesy as correct answers. A teacher would be most unfair to condemn an answer arbitrarily merely because it was not what he expected. Perhaps the question was crudely stated and the pupil misinterpreted it. Or the pupil may have had true understanding but found oral expression of it difficult. Again, his answer might have been wholly or partially correct and the teacher might have been wrong. Sometimes there are actually two sets of correct answers possible. And even if the pupil is completely wrong there is no excuse for sarcasm, scolding, or contemptuous comments. Everyone makes errors and holds wrong viewpoints.

Chorus answers are undesirable. For one thing, if several pupils can shout an answer in unison with little reflection, the question is probably too simple to be worth asking. Secondly, acceptance of a chorus answer encourages habits of uncontrolled talking. Chorus answers can be discouraged by preceding each question with the name of the pupil who is to answer it. This notifies other pupils that a

selection has been made. This technique need be used only if pupils are in the habit of making chorus answers.

Good questioning proceeds at a brisk pace. Active participation is limited to one pupil at a time; the others must sit quietly without much hope for expressing themselves. Should the questioning drag or the answers become involved, some pupils are certain to begin thinking of other things.

Questioning is more effective if the questions have been written out beforehand. More attention can be given to the construction of the questions and to the type of answers expected. Less class time is needed for the teacher to state the questions. Some teachers write their questions on three-by-five cards, one to a card, which may then be organized in any fashion and shuffled through quickly as needed.

Every possible means should be used to encourage maximum participation. Questions should be given in clear, firm tones even when directed to nearby pupils, in order that all pupils be able to follow the line of questioning. Answers from pupils in front seats, often inaudible at the rear, should be repeated by the teacher so that pupils everywhere in the room can understand. The teacher should keep his eyes upon the class as a whole in order to recognize pupils who wish to contribute and to be alert for signs of inattention. He should be very careful not to allow himself to be drawn into a special discussion with one or two pupils or to allow a few pupils to dominate the activity.

Question-answer sessions should be terminated before pupil attention begins to shift. This is a type of activity that does not hold the attention of all pupils for very long. By the end of ten minutes the minds of most of the pupils will have wandered at one time or another and the numbers not paying attention at any one time will be rapidly increasing. Soon the numbers participating are too small to justify the time being spent and the ones not participating have become so many as to represent potential disciplinary trouble.

CLASSROOM DISCUSSIONS

By definition a discussion is a talking over of subjects from various points of view. As such, discussions have some important functions in the science program. Unfortunately, teachers often apply the term "discussion" to almost any type of talking in the classroom—questioning, lecturing, stating procedures to be followed. They say, "We will now discuss," when they mean, "I am now going to lecture to you." They say, "Let's discuss how we will do the experiment," meaning, "I will now tell you precisely what to do." When they say, "Let's discuss our findings," they mean, "I will now tell you what conclusions

to draw." The remark, "Let's discuss this new topic," often means, "I will now ask you some questions and you will try to guess the answers."

Because of the lack of definitive thinking about discussions, teachers commonly fail to think through the purposes of the various types of verbal activities. They fail to take full advantage of these verbal activities and instead employ a great deal of time in purposeless conversation.

In a true classroom discussion, all pupils are free to express their viewpoints. This implies that pupils must first have a background that provides them with viewpoints. They cannot discuss something about which they know nothing. Secondly the definition implies that the teacher does not dictate or seek to influence the opinions of the pupils as he leads the discussion. If he does so, he is actually lecturing, no matter how well he disguises the act.

True classroom discussions, though limited in application, have an essential place among science teaching techniques. Free discussion is the most effective means for raising problems that challenge pupils. Free discussion is ideal for verbal summaries. It is the only means for bringing about teacher-pupil planning. It is essential for consideration of controversial issues.

Good classroom discussions are not at all easy to conduct. It requires great skill to keep attention centered upon one point, without discouraging those who make irrelevant remarks, permitting a few pupils to monopolize the conversation, or influencing opinion. Leading a profitable classroom discussion is the most difficult of all classroom techniques.

Initiating a unit with a discussion. Discussions are commonly used for the motivation of pupil activities. They are effective when they raise problems that the pupils believe to be worth solving.

"I know that several of you smoke," Mr. Thomas announced to his biology class. "And I know that more of you will be smoking in coming years. I am sure also that you have heard various arguments against smoking. Let's try to find out what's behind some of these arguments to see if there is any truth in them."

For the next several minutes the pupils volunteered such information and misinformation as they had picked up incidentally from readings and conversations. They soon concluded that none of them knew much about the subject.

"I'm going to read about smoking," said one girl. "Can you tell me where to look, Mr. Thomas?"

Mr. Thomas mentioned a few sources of information. Other pupils expressed an interest in further investigations. A girl whose father had given up smoking because of ulcers said she would ask the doctor what smoking did to her father. Her suggestion reminded pupils of this source of information.

The discussion ended in a planning session, with pupils volunteering to investigate various aspects of the problem both by reading and by interviews with parents, doctors and insurance company representatives.

Mr. Thomas made an excellent choice of a topic for discussion by adolescents. Many adolescents are faced with the immediate problem of whether to smoke or not to smoke. Most of them resent being told that they must not smoke but they are generally grateful for an opportunity to consider the several aspects of the question. The topic, as introduced by Mr. Thomas, was one for which the pupils had sufficient background to make true discussion possible and one about which some of them had well-formed opinions. On the other hand the pupils recognized their lack of positive information, and they engaged in sufficient controversy to feel a sincere desire to investigate farther.

Controversial issues such as smoking generally make good topics for problem-setting discussion periods. Matters of current interest can also be used to initiate this type of discussion. Teachers may set up exciting demonstrations or display unusual materials to initiate problem-setting discussions.

Mrs. Harvey brought to school a large paper wasps' nest which she had found in the country during the weekend. A few of the pupils had seen such nests before and recognized it as a wasps' nest—though some of them insisted it was a bees' nest. Mrs. Harvey gave each pupil a piece of the covering and asked for a description of it. The pupils described it as paper-like and proposed several possible origins. Then Mrs. Harvey cut open the nest and displayed the interior. Some dead wasps found inside were put in a glass dish and passed around. The pupils discussed the possible function of the comb, proposing that it was used for honey even though none was found in the comb. The pupils then listed a number of questions about the nest and its makers that they would like to investigate.

Some teachers form the habit of beginning each new topic with a discussion. This is not wise. Pupils do not always have sufficient background or sufficient interest for a discussion to be profitable in the early stages of a study. There are other approaches to science that are generally more valuable. Initial discussions should be used sparingly and only when conditions are suitable.

Planning sessions. When pupils are to plan their activities with a minimum of guidance by the teacher, they need opportunities to talk over procedures, make decisions, and allot responsibilities.

The city was suffering from a serious water shortage. Eighth grade pupils had heard so much about the problem, at home and in the newspapers, that they showed a strong interest as soon as Mrs. Evans mentioned the topic. Nevertheless they had few concrete ideas about the causes for the shortage and knew little about either their own water supply system or the nature of water storage in general.

Mrs. Evans suggested that the pupils list the questions thoy would like to answer. She then suggested a general reading assignment in the textbook; the reading broadened the scope of the pupils' thinking and resulted in the addition of more questions to the list.

The pupils began making suggestions of things to do. Some suggested making a map showing the watershed, the storage reservoirs, and the aqueducts taking water to the city. Pupils suggested asking the local newspaper for rainfall records. They suggested making a bulletin board display of pictures of the water system of the city. They suggested experiments and demonstrations taken from the textbook readings, and studies of the amounts of water needed for washing dishes, for taking baths, and for flushing toilets. Mrs. Evans suggested measuring the water lost through a dripping faucet.

Thus the suggestions accumulated, some of them giving rise to new questions to be answered. Finally, the pupils portioned out the tasks, each individual volunteering to work alone or with one or two others on a special project.

The teacher who uses this technique for planning must be willing to permit his pupils to follow up their own suggestions. He may have plans of his own and he may make suggestions to amplify or round out the ideas of the pupils, but if he initiates the discussion fully determined that the pupils will adopt the plans he has in mind, he is wasting time and energy in a hypocritical attempt to be "democratic."

Discussions of results. Group discussions of the significance of data can be among the most worthwhile activities of the science program. The pupils have gained comparable experience backgrounds through their field or laboratory work and are now able to communicate effectively with each other. They are able to bring their collective judgment to bear on the problems, thinking through the issues, studying exceptions and discrepancies, and qualifying the conclusions they make. Often they find so many weaknesses in their data that they are desirous of repeating their observations under more carefully controlled conditions.

During a laboratory exercise ninth grade pupils had tested the forces needed to draw loaded toy trucks up sloping boards. They had concluded that less force was needed to draw the trucks up the boards than to lift them directly.

After doing some reading, however, they discovered that the mechanical advantages which they had determined did not agree with those the textbook obtained. Friction was obviously the causative factor and the pupils wanted to use the low friction metal rollers described in the text. After the pupils had used these rollers they were more satisfied with their results.

The accumulated data now led to a consideration of efficiency and new problems arose. Efficiency seemed to increase as the slope increased; new experiments were planned to test this using various devices, metal rollers, toy trucks, blocks of wood, roller skates.

Discussion of the results obtained in the first experiments gave these pupils an understanding of some of the factors that affected their data. They were then able to devise methods for refining their experiment. Even had they been unable to incorporate the refinements, they would have understood the need for qualifications of their conclusions.

It is through discussion of results that pupils best see the workings of the scientific method. Complex directions for highly refined experiments are apt to be followed in cook-book fashion with little appreciation for the refinements involved. But simple experiments with their obvious limitations enable pupils to put the scientific spirit in action.

Discussions for summary and review. Generally teachers conduct reviews and oral summaries by question-answer techniques, because they prefer that the learnings be organized according to certain established patterns. If, however, a teacher is willing to let pupils develop their own form of organization on occasion, he may provide short periods of free discussion for this purpose.

Pupils are usually capable of dealing with limited amounts of information, especially if these have been recently covered by class work. They may not have the maturity to conduct major summaries and reviews without aid. Therefore, during a major review, a teacher may provide an over-all pattern to guide the work and permit the pupils to deal with the segments of the outline as they wish.

Mrs. Lowell occasionally employs what she calls "buzz sessions" for review purposes. She provides a list of topics making up the unit to be reviewed. The pupils work in groups of three or four, each group selecting a topic. In their "buzz sessions" the pupils decide what they have learned about the topic. Later, they report to the class and stand ready to answer questions.

Techniques for leading discussions. During a classroom discussion the teacher serves as moderator. In brief his duties are as follows:

1. To keep the discussion moving
2. To keep the discussion pertinent to the topic under consideration
3. To encourage all pupils to participate
4. To keep some pupils from dominating the conversation
5. To acknowledge all contributions
6. To reject irrelevant comments without giving offense
7. To summarize frequently and keep the picture clear
8. To end the discussion when interest begins to wane.

A discussion leader must be able to handle many different types of situations with tact and diplomacy. When several pupils wish to speak at once it is his task to select one without discouraging the others. He must be able to listen to rambling and irrelevant discourses with patience, end them as promptly as possible without discourtesy, and then steer attention back into proper channels.

The nature of the topic has much to do with the success or failure of a discussion. Some topics lend themselves to discussion, others do not. First of all, the topic must be one about which the pupils have some knowledge. Only thus is it possible for them to do more than speculate idly. Controversial issues on which the pupils take stands often make good topics for discussions. These issues may deal with matters of current interest such as the fluoridation of drinking water. They may deal with such perennial arguments as the harm in drinking coffee. They may deal with conflicting laboratory data.

Topics that deal with indisputable facts do not lend themselves to discussion unless the pupils are uncertain about these facts. It would not be possible, for instance, for pupils to discuss the properties of air if each knew about these properties. The only verbal activity they could engage in would be to review the properties.

Physical conditions influence the effectiveness of discussions. Pupils should be able to hear and see each other. The most effective set-up is a circular arrangement of chairs. If seats are fixed, the teacher must take pains to repeat the statements of pupils in front seats for the benefit of pupils in the rear of the room. Otherwise the latter lose the direction of the conversation.

A discussion leader is frequently faced with the problem of seemingly irrelevant, sometimes facetious, remarks. He will find it good policy to treat all remarks as though they were serious in intention. A teacher cannot follow the workings of every pupil's mind. Perhaps a point raised in discussion has set a pupil thinking along a channel not anticipated by the teacher. This pupil may then blurt out a statement that to others seems irrelevant, often ridiculously so. Simple courtesy de-

mands that this pupil be given a word of recognition and perhaps a brief explanation of why his point does not fit the present discussion. If the pupil is serious, he will understand and not be hurt. If he meant to be facetious, he gains little satisfaction from his effort.

During discussions, pupils are apt to ask many questions, both relevant and irrelevant. By tradition a teacher feels obligated to answer as many of these as he can. Perhaps this tradition dates back to the time when there were few books and the teacher had to act as an authority.

Actually, the practice of trying to answer all questions is educationally unsound. Few teachers have the background to answer carefully and accurately the majority of questions asked. More important, the answering of a question tends to bring to an end the intellectual activity that initiated the question. If a pupil asks, "Will this piece of pumice float?" and is told "yes," there is nothing more for him to do. he may even forget the information in a short time. But if he is told, "Why don't you try it and find out?" he is at the beginning of a real learning situation.

Relevant questions can be used to set the stage for problems to be solved by the class, by groups, and by individuals. They should be welcomed. Irrelevant questions may be more troublesome. Sometimes the interested pupil may be detached from the group to work on the answer to the question. More often, the teacher must explain why his question cannot be dealt with at that time and, if possible, arrange for the pupil to follow up his interest later. Much depends upon the nature of the question, and much depends upon the teacher's ability to see potentialities in the question.

The effectiveness of class discussion generally drops off sharply after several minutes. Pupils have difficulty maintaining a high level of attention during discussion activities. Only one pupil can participate actively at a time; the others must sit quietly. At the very best, were the pupils to speak in turn for but ten seconds each, five minutes would elapse between turns. Pupils would need unusual stimulation to keep their attention centered upon a topic for this long a time.

What happens in practice is that a few pupils dominate the discussion and the others contribute little. Some of the latter listen idly, some daydream, some read or write surreptitiously, some whisper to each other, and the more active of them move about uncomfortably. If the discussion continues too long, some of the latter may become disturbing influences.

Mr. Turin, a student teacher, tried to conduct a discussion of safe driving practices for the last twenty-five minutes of the class period. For fifteen

minutes the discussion seemed to proceed smoothly, but actually only six pupils contributed significantly. A few others occasionally raised their hands. One girl read a novel; a boy read a comic book. One boy worked on an English report. The others wriggled about, looked out the window, whispered, and gave but fleeting attention to the topic under discussion.

Ten minutes before the end of the period two girls began to giggle. A boy shouted "Quiet!" in mock authoritative tones. The girls stopped momentarily but soon resumed. Class attention was now distracted and confusion grew. Two boys talked audibly. A boy punched another boy and the latter yelped. A girl pretended to slap a boy's face for some derogatory comment.

Mr. Turin finally shouted for order. In the momentary silence he scolded the class and voiced threats about detention room. Noticing the boy reading the comic book he confiscated the book and put it in his desk.

The last few minutes of the period were completely disorganized. Pupils moved about and talked aloud at will. Scuffling broke out a couple of times. Some of the pupils walked about the room. The boy who had lost his comic book muttered continuous threats in an undertone and added to the din by deliberately dropping a book, scraping his chair about, and slamming books into his desk.

Blame cannot be attached to the pupils for Mr. Turin's trouble. They had cooperated for fifteen minutes, at least to the extent of keeping quiet. The fault lay with Mr. Turin, who had extended the conversation longer than was profitable. He attempted to keep pupil attention by scoldings and threats and minor punishments that served only to antagonize the pupils. They took their revenge in a multitude of petty but annoying ways.

A discussion leader must give as much attention to the pupils who do not participate as to those who do. He must try to draw all pupils into the discussion. When he begins to fail, he should bring the discussion to a close.

Pupil-led discussions. All that has been said about teacher-led discussions applies equally to pupil-led discussions. Such problems as suitability of topic, participation and duration of the discussion are of the same importance. In addition, a pupil leader has a special handicap because he lacks authority. In class discussions, his fellows may not be inclined to cooperate with him even when the teacher is present. They may speak without being recognized. They may interject frivolous comments.

When attempting pupil-led discussions for the first time, it is well to search out the best natural leader, one who has the respect of his fellows, who is articulate, and who will accept the responsibility

seriously. Once a successful pattern for behaviour has been established, other pupils may be employed as leaders; but if the wrong choice is made the first time, it may be very difficult for later discussions to succeed.

Most successful pupil-led discussions center about experiences that are fresh in the pupils' minds. Many teachers employ them only for summary and review. However, there are situations in which pupil-led discussions are effective for planning attacks on problems, particularly problems that are an outgrowth of previous work.

Mr. Wharton had been assigned a small physics class of sixteen serious-minded pupils. He was able to give them many responsibilities he might not have given to a more typical class. One day, after the close of a unit on light, he passed out duplicate copies of an instruction booklet for a well-known make of camera. When the pupils had skimmed through the booklet he announced:

"I'm going to let you organize this next unit on photography yourselves. Jack, will you be the group leader and run a planning session to decide what you are going to do?"

Under Jack's leadership the pupils formulated a number of problems to work on—the meaning of depth of focus, focal lengths of lenses, nature of camera lenses, significance of the F-openings, color rendition and light intensity factors. They divided into groups and began working on the topics, devising experiments to help with their understandings.

Small group discussions are often more successful than class discussions. There are more opportunities for pupils to participate, and fewer personality clashes. In general there is less incentive for attention-getting acts. However, a teacher cannot keep in touch with the decisions of the pupils and must assign all responsibilities to the group leaders.

A description of Mrs. Lowell's "buzz sessions" as used for review has already been given. Some teachers commonly employ small group discussions for project planning.

Mr. Scardamaglia's eighth grade science class planned to set up a weather station using homemade instruments. The pupils divided themselves into small groups, each of which chose a specific instrument to build. Mr. Scardamaglia allotted fifteen minutes of the period for planning sessions. He did not appoint leaders but allowed the groups to appoint their own leaders.

Small discussion groups may be detached from the main body of the class to plan special projects or to organize their findings.

Several pupils in Mrs. Lowell's eighth grade science class expressed an interest in the outer atmosphere. Mrs. Lowell suggested that they do some outside reading on the topic. On the following day, four pupils reported that they had begun such readings.

Mrs. Lowell accepted this effort as an indication of true interest and appointed the four as a special committee to work on the topic. The pupils worked at the rear of the room for about half the period, doing additional reading and organizing their findings. On the following day they were given time to prepare a final report. The final copy of their report was duplicated and given to the other pupils of the class.

Suggested activities

1. Write out directions that might be given orally (1) for a reading assignment in a text book, (2) for a simple laboratory exercise, (3) for a notebook exercise, (4) for getting ready for a test.
2. Prepare a brief account of one of your own experiences that you think might help pupils understand a specific scientific principle.
3. Write out a set of questions you might use in guiding a discussion of the results of a field observation or a laboratory exercise.
4. Observe a science teacher leading a class discussion. What percentage of the class participates in the discussion? What percentage dominate the discussion? What percentage pay little or no attention to the discussion?
5. List ten topics that you think would lend themselves well to general class discussion.

chapter 11 TESTS AND TESTING

Taking a test can be an exciting experience, one to which pupils look forward with enthusiasm. There is stimulation and a challenge to the imagination in a good test. Unfortunately, teachers do not always know how to make their tests an integral part of their teaching. They use tests for a single function —the determination of grades. Tests thus become whips held over the heads of pupils to induce them to further efforts. Small wonder that many pupils look upon tests with dread.

THE USES OF TESTS

Tests may be used throughout a unit—at the beginning, at the end, and in between—each time with different purposes in mind. Sometimes a single test may serve two or more purposes. Tests should usually be used as part of the teaching process. Only occasionally are they needed for determining grades and never should test scores be used as the only measures of success in a course.

Pretesting. A pretest attempts to discover the status of pupils at the beginning of a unit in order that the teacher may know where teaching should begin. Perhaps he wishes to know something of the experience background of his pupils; informal questioning—"Who has seen an electromagnetic crane?" or "Who has been to Gilbert Lake State Park?" —may serve his needs.

A teacher may wish to test the information background of his pupils.

His questions should be formulated with care; wording and phrasing are important. They should not be vocabulary tests but tests of understandings. In formal pretesting, short-answer questions permit the coverage of the widest range of information in a limited time. Of the short-answer type, true-false questions require the least time for construction, administration and checking.

Formal pretests need careful construction. There is always danger that they will be lengthy, academic, and discouraging. It is wise to include a generous selection of easily answered questions in order that pupils may find satisfaction in their achievements. Wording and phrasing are important because at the beginning of a unit the pupils have not developed a common vocabulary; pupils may have an understanding or an experience but may not be able to identify it if questions employ technical terms. Generally, pretests should not occupy more than fifteen or twenty minutes for completion, lest an unfavorable attitude towards the subject be developed.

A spiral organization of test items may be helpful. The first and simplest questions make a hasty sweep of the area being previewed, the second set of questions covers much the same ground but in greater detail. A third set, if used, may test finer details and be much more difficult. With this organization, the discouragement factor has less influence.

Below is an example of a true-false pretest used in a ninth grade science class to open a unit on the senses. Notice the spiral organization of items, beginning with matters commonly observed by everyone and ending with information generally acquired only from books or from school situations:

Answer the following questions with *true* or *false*.

1. Most knowledge is gained through the eyes.
2. People have either brown eyes or blue eyes.
3. There is one eyelid for each eye.
4. Tears wash dirt from the eyes.
5. Only one eye at a time is used when looking at a nearby object.
6. Sunglasses reduce the amount of light entering the eye.
7. Objects can be seen more clearly by day than by night.
8. The eyelids stay open for only a few seconds at a time.
9. There are always tears in the eyes.
10. Eyeglasses make objects look larger.
11. Colors of objects can be determined by starlight.
12. A person can see clearly all objects in front of him without moving his eyes.
13. Eyeglasses help a person see objects that are far away more clearly.
14. The black spot in the center of the eye becomes smaller in the dark.

15. Both eyes always move in the same direction when they turn.
16. The use of two eyes at once helps a person judge distance.
17. Light enters the eye through the black spot in the center.
18. There is a lens in the eye.
19. The black spot in the center of the eye is called the pupil.
20. The colored part of the eye is called the iris.

It is sometimes interesting to repeat a pretest at the end of a unit. This gives the teacher an opportunity to compare scores for determining progress. However, it must be remembered that a pretest should be constructed in terms of the vocabulary, knowledge and interests of the pupils at the beginning of a unit. A final test does not usually make a good pretest, and a pretest rarely makes a good final test.

Tests for motivation. By accident or design many tests contain controversial questions which give rise to interesting problems. These problems may be used to initiate new lines of investigation.

A biology test contained the following item:

"Life processes in the animal embryo begin with __________"

Several pupils wrote in the word "birth" and during class consideration of this item argued heatedly in its favor. A number of pupils evidenced incomplete knowledge of pre-birth conditions.

The pupils accepted the teacher's suggestion that they plan a series of investigations about the development of the human embryo. They proposed the following questions:

1. *Can an embryo move? If so, when does it begin to move?*
2. *Does an embryo breathe? If so, how does it breathe?*
3. *Does an embryo's heart beat? If so, when does it begin?*
4. *Can an embryo die?*
5. *Does an embryo have to digest food?*
6. *Can an embryo feel? Does it think?*

During their investigation the pupils referred to a number of books. Some asked questions of their mothers. Three girls interviewed a doctor. Two interviewed a nurse.

To utilize controversial questions, the teacher should ask pupils to look over their papers immediately after answering them. Then pupils are better able to recall the thinking that led them to their decisions.

Pretests may be designed expressly for initiating discussions. Such tests may include questions about common superstitions, or about matters of importance to the community, or about other controversial issues. For example:

True or false?

Hot water will freeze before cold water.

Sewage in the river improves fishing.

Fluoridation of drinking water is advisable.

It is not necessary that there be final answers to the questions on such a pretest. Sometimes answers can be obtained by experiment or field observations. In other instances, evidence supporting different points of view may be collected.

Page 267 shows a complete pretest used in an eighth grade class to initiate discussion about earth changes. A similar test may be constructed to arouse speculation about the topographic features around any school.

Motivating pretests, like other types of pretests, should be short. The terms used should be familiar to the pupils. The material dealt with should lie within the experience backgrounds of the pupils.

Some pupils are stimulated by progress tests. Such tests should be given frequently and regularly. Pupils may score their own papers and keep their own records. The preparation of a battery of progress tests is useful for individualized study units; pupils take the tests when they feel ready and score themselves. Self-scoring tests should have simple questions that have positive answers so that pupils do not need to refer constantly to the teacher for decisions about doubtful answers.

Tests for review and drill. This use of tests needs little explanation. In a series of tests it is commonplace to include review questions as well as questions on current material. Important questions may be repeated a number of times. Sometimes a test is made up entirely of review questions.

Review and drill tests may be written or oral. Short oral tests are excellent review instruments but, because only a few pupils can participate at one time, interest is apt to lag after a few minutes of questioning. Oral review tests should be conducted briskly and with little discussion of answers. It is well to write out the questions beforehand to insure simplicity and directness.

Tests designed solely for review and drill need not be graded by the teacher, but written papers may be collected for further analysis. It is usually wise to direct pupils to check their own answers so that they recognize their own mistakes and clear up misunderstandings. Usually checking is done as a uniform class activity but pupils may be asked to check their papers and correct any mistakes as an out-of-class assignment.

Testing pupil achievement. Great weight is often attached to the scores pupils make on their tests. Test scores usually determine a pupil's status in school and often decide his future. Obviously the tests used should be constructed with the greatest of care. "Trick" questions and unfamiliar test items are unjust. A fair test deals only

A PRETEST USED TO INTRODUCE AN EIGHTH GRADE UNIT ON EARTH CHANGES IN AN ITHACA, N.Y., SCHOOL *

Which of the following statements do you believe to be the most probable? Which do you consider impossible? Mark those you think probable with a plus sign. Mark those you do not believe with a minus sign.

1. Cascadilla gorge
   - ____ has always been as *deep as it is now.*
   - ____ is being dug deeper every year.
   - ____ was once a much smaller *gorge.*
   - ____ was dug out by a glacier.
2. Enfield Glen
   - ____ was changed by the last flood.
   - ____ is cut from rocks that once were mud and sand.
   - ____ would be deeper if the banks were made of *clay.*
3. Cayuga Lake
   - ____ is filling up.
   - ____ may someday disap*pear.*
   - ____ was here at the beginning of the world.
   - ____ is *a dammed-up river* valley.
4. Ithaca is built
   - ____ upon soil that came from nearby hills.
   - ____ on soil that came from Canada.
   - ____ on *a delta.*
   - ____ on soil carried in by man.
5. The airport is built
   - ____ upon a natural plain.
   - ____ *upon a swamp.*
   - ____ upon part of Cayuga Lake.
   - ____ upon soil brought in by *man.*
6. The site of the Cornell campus
   - ____ was once beneath the sea.
   - ____ was once covered by ice and snow all year around.
   - ____ *has moved up and down* in the past.
7. The salt mines
   - ____ contain salt hidden *there by early man.*
   - ____ are connected with the salt water of the sea.
   - ____ contain salt from a *dried-up lake.*
8. The cement plant was built at Portland Point because
   - ____ *there is plenty of water.*
   - ____ there is salt.
   - ____ there is limestone.
   - ____ there is a view.

* Thurber, W. A., "A Challenging Pretest," *Science Education*, April, 1943

with material familiar to pupils and, if it is a verbal test, it uses only language the pupils understand. A teacher must be sure that he is testing truly important outcomes. And he must be sure that he is not ignoring important achievements because of the limitations of his test instruments.

Teachers are constantly encountering the limitations of their tests. A boy may be able to show with a carburetor in his hands all the important parts, describe their operation, and demonstrate adjustments. Asked to write down his knowledge he may fail completely. He may not even be able to explain a diagram of a carburetor.

Undeserved comparisons are often made because tests are not wisely chosen. One boy may be able to set up electric circuits but be unable to discuss electrons. Another boy may talk glibly about electrons but not know how to wire a doorbell circuit. But the first boy is certainly as accomplished as the second.

Verbal tests contain certain variables that must not be ignored in constructing tests for evaluation. (1) A teacher may not express precisely what he wishes to find out from the pupil. (2) The pupil may not interpret the question correctly. (3) The pupil may not express his knowledge adequately. (4) Finally, the teacher may misinterpret the pupil's answer. It is thus possible for a pupil to fail a test while possessing the essential information.

Verbal tests are best adapted to measuring factual information that has been learned through verbalization. When pupils gain information through direct experiences, as is the case in so much of the science program, they should be tested with a non-verbal test, or else they should be helped to verbalize their understandings adequately before being tested.

To use verbal tests justly, pupils should be given ample practice with questions identical with or closely similar to those with which they will be tested. Frequent review and drill tests provide this practice. Pupils should know precisely the range of content a test is to cover and the areas of major emphasis on the test should have received major emphasis during class time. It is most unfair to include material that has been touched on briefly or not at all during class work.

Frequent evaluation tests give a more accurate picture of achievement than do a few major tests. Four or five short tests cover the same material as a long test without allowing the influence of fatigue, sickness, and emotional tension to become so important.

Using tests to evaluate teaching effectiveness. Test results give a clue to the effectiveness of some of the procedures used by a teacher. Many variables must be taken into consideration but generally a set of high

scoring papers indicates success in teaching the material included in the test, and a set of low scoring papers indicates failure in teaching.

When individual test items are analyzed, specific strengths and weaknesses may be pointed out. Again the several possible factors must be considered. High success for a certain item may indicate good teaching or it may indicate knowledge acquired from previous experiences. Low success may indicate poor teaching or faulty test construction. A later section will give detailed help in analyzing test scores.

Teachers should be conservative in claiming success for their teaching procedures on the basis of test scores alone. It is possible for pupils to have high test averages and yet end the school year with little satisfaction and even with distaste for science. Overemphasis on memorization of facts for the purpose of passing verbal tests tends to remove a science course into an abstract realm where pupils see little value to what they are doing. On the other hand, even if pupils have worked hard on special projects and can present many tangible evidences of success, general failure on verbal tests represents a serious problem. With the weight attached to the results of verbal testing, pupils cannot afford to fail their tests. And their failure to pass tests usually does represent a teacher's failure to help them verbalize their learnings.

Teachers are sometimes tempted to excuse themselves from the responsibilty for a number of low test scores as long as a few pupils do very well. Careful study of the pupils is apt to show that the few who succeeded had acquired their knowledge in previous years or had superior backgrounds that enabled them to learn despite poor teaching. Apparent laziness and incompetence on the part of the others might have disappeared with a different teaching approach.

TYPES OF TEST ITEMS AND THEIR SPECIAL PROPERTIES

There are many type of tests, one for almost any purpose. Some of the types are as interesting to do as puzzles and are used as such in picture magazines and popularized science books. There is a sufficient variety of test items to keep the testing program interesting.

Test items may be divided into three categories—purely verbal tests, tests that involve pictures and diagrams, and tests that make use of actual materials. Each type has its own values and each has serious limitations. The last named type most closely approaches reality and can measure learnings that verbal and picture tests cannot evaluate at all. However, these tests generally are difficult to set up and administer. Verbal tests depend upon the interpretation of words. Pupils who lack fluency with words are penalized by them. However, when

verbalization is considered an important outcome, these tests are valuable. Picture tests represent something of a compromise between verbal tests and tests based on actual materials. They are several steps removed from reality but they do reduce some of the emphasis put on words in the purely verbal tests.

Performance tests. Performance tests measure a pupil's ability to carry out certain operations in science. The needed materials are placed before the pupil together with a statement of the problem to be solved. The pupil is expected to solve the problem and demonstrate the end result. He may or may not be expected to explain the reasons for his operations. He may be scored on the end product only, or on each step, or on his explanations, or on all three.

Performance tests come closer to measuring certain desirable outcomes of the science program than do most other tests. Unfortunately, not much experimentation with this type of test has been carried out and only a limited number of satisfactory problems have been developed. Most of these are in the area of electric circuits.

Example 1. A pupil is given a length of glass tubing, a gas burner, and a match. He is told to make a right angle bend in the tubing.

Example 2. A pupil is given a miniature electric lamp, a dry cell, and a knife switch. A card with the materials reads, "Connect these so that the lamp lights when the switch is closed."

Advantages. Little or no verbalization is required. Manipulative ability is tested. Understandings that are difficult to verbalize are tested. Pupils who do poorly on verbal tests may receive recognition for their achievements.

Disadvantages. This type of test is difficult to administer to large groups. If duplicate sets of equipment are used, a large amount of materials is needed. Otherwise, cumbersome rotation systems must be used so that each pupil gets a turn.

Identification tests. This type of test measures a pupil's ability to carry out identification procedures. He is given one or more unknown specimens and the materials he will need to test their properties. He is scored on the accuracy of his identification.

Example 1. A pupil is given ten unfamiliar mineral specimens, together with equipment for determining such properties as hardness and streak. He is asked to give the names of the specimens.

Example 2. A pupil is given five bottles of solutions and litmus paper. He is asked to determine which solutions are acid, which are neutral, and which are alkaline.

Example 3. A pupil is given four unfamiliar leaves and a key to leaf identification. He is asked to key out the leaves to determine their names.

Advantages. As with performance tests, pupils are working with actual materials. The test measures their true understandings of procedures. Verbalization has little place in the test.

Disadvantages. As with performance tests, adequate materials must be provided. To be fair, the specimens must be unfamiliar to all pupils; this may be difficult to arrange.

Recognition tests. In this type of test, familiar materials are presented to the pupils who are then to give the proper name of each specimen. Usually the specimens are numbered so that the pupil may write the name of the specimen opposite the corresponding number. Sometimes responses are oral.

Example 1. Twelve different flowers are placed in glass jars to which numbered labels are glued. The jars are placed in order on the laboratory tables. Pupils number their answer sheets from one to twelve and move in turn from specimen to specimen, writing down the name of each.

Example 2. Twenty-four trays, each containing identical sets of ten numbered rock specimens, are given to the pupils. The pupils write down the names of the specimens.

Example 3. Ten large mounted birds are held up one at a time before the class. The pupils write down the names of the birds in the order they are presented.

Example 4. Ten different insects are mounted in glass topped boxes, one to a box, and the boxes are given numbers. The boxes are passed about the class and the pupils are expected to write down the name of the order to which each specimen belongs.

Advantages. This type of test measures a pupil's ability to recognize and name actual materials. It is far superior to any purely verbal tests designed for the same purpose.

Disadvantages. The naming of specimens is a minor goal of science but is given great weight by this type of test. These tests have some of the administrative problems that handicap all tests using science materials—difficulty in providing adequate materials, storage of materials, noise and confusion during the taking of the test.

Name association test. A recognition test may be simplified by giving the pupils lists of names of the specimens to be presented. The pupils write the number of each specimen opposite the proper name. There may be more names than specimens, as in matching questions.

The association of names and specimens may be considered sufficient. If recall of names is desired, this type of test may be used as a teaching test to give early practice in naming of specimens. It may be followed by the recall type of recognition test described above. Ad-

vantages and disadvantages for this form are about the same as for the standard recognition test.

Modified recognition test. The following is an excellent test to determine what pupils know about science materials. Specimens are presented together with questions about the characteristics of the specimens. Identification may be requested but sometimes the questions are formulated so that naming is not essential.

Example 1. A tray contains a fossil trilobite and a card with the question, "Is this group of animals common, rare, or extinct today?" The tray is passed from pupil to pupil for examination.

Example 2. A specimen of hard maple lumber has tacked to it a card with the question, "Is this wood used most commonly for furniture, for paper pulp, or for framing houses?" The specimen is passed about the class.

Example 3. A microscope shows a single stomata in a bit of leaf epidermis. Beside the microscope is a card with the question, "Of what use is this structure to a plant?" Pupils take turns looking through the microscope.

Advantages. Here is a test that emphasizes knowledge of characteristics and uses more than identification of specimens. It eliminates much of the dependence on words and pictures and diagrams that are typical of most test questions. The material covered can be truly practical. Pupils like this type of test. It is useful for self-evaluation. The specimens may be kept in a drawer or box for pupils to use when they have completed certain assignments. A few specimens may be put on a side table for pupils to use as they wish.

Disadvantages. The test is apt to be difficult unless familiar materials are used. If the answer depends upon identification as well as upon knowledge of the characteristics, a pupil may fail to answer it correctly for either of two reasons—inability to identify the specimen or lack of information about it. The administrative problems involved are the same as those for recognition tests.

Picture tests. Pupils may be given pictures with accompanying questions. These pictures may be clippings from magazines and old texts. The teacher whose hobby is photography may take pictures of local features, especially those seen on field trips, and prepare enlargements for testing purposes.

Pictures may be stapled in filing folders together with a set of questions to be answered. Then the folders may be passed from pupil to pupil. Duplicate folders reduce the time needed for taking the test. After the test, the folders may be stored in a locked filing case for use in succeeding years.

Example 1. A picture of an elm tree without leaves is pasted to a card. A question on the card reads, "What is the name of this tree?"

Example 2. A photograph of a transformer station is stapled to the left side of a filing folder. Letters identify some of the structures. On the right side is stapled a typewritten sheet bearing the following: "We visited this transformer station last week. What is the voltage of the electricity at A? What is C called?" Similar questions follow.

Example 3. A clipping from a magazine shows a steep hillside, and a valley with streams and lakes. Several features are identified with letters written with colored ink for contrast. Question sheets contain blanks for the answers and such questions as the following: "At which place will stream erosion be most rapid?" "Where will sediments be deposited?" "Where would you expect to find the clearest running water?"

Advantages. This type of test has some of the advantages of tests using real specimens, especially when the pictures deal with features seen by pupils in their class work. It is an excellent way to measure information gained during field trips. The test materials are more easily stored than are actual specimens.

Disadvantages. A major weakness of the test is the limitations of any pictures. Pupils must interpret two-dimensional images into three dimensions. The pictures must be very good if grades are to be recorded.

Diagram and model tests. A model may be displayed in front of the class, or a diagram may be provided on a chart, the blackboard or on duplicated sheets. Letters or numbers identify various structures. Duplicated question sheets may be provided or the teacher may point to certain structures in turn while asking about each

Example 1. The teacher displays the enlarged model of an eye commonly seen in classrooms. He dissects the model and holds up several parts in succession. Pupils are asked to write down the name of each part.

Example 2. A chart shows a diagram of the human digestive system. Pupils are given sheets with the names of the organs. They are asked to write by each name the number that identifies the corresponding structure on the chart.

Example 3. Pupils are given sheets on which are printed the diagram of a lift pump. The valves are identified with letters. Beside the diagram is the question, "On the upstroke of the piston, which valve is open and which valve is closed?"

Advantages. Sometimes specimens and pictures are not available, or a knowledge of internal structure is to be tested. Then diagrams serve a purpose. They are better than strictly verbal tests when questions cannot be formulated clearly in words.

Disadvantages. Models and diagrams are far removed from reality. They are apt to be very difficult to interpret, especially for pupils who lack the ability to think in the abstract. Pupils should be thoroughly familiar with each model or diagram before it is used for testing purposes.

Drawing tests. Pupils may be asked to make drawings of some object or device they have studied during class work. Labels and explanations may be required in addition.

Example 1. Make a drawing of a spider, showing the major parts of the body and where the legs, palpi, and spinnerets are attached.
Example 2. Make a diagram of the apparatus used to prepare sodium hydroxide from table salt. Label the parts.
Example 3. Make a cross-sectional diagram of an electric light bulb. Show with a heavy line the path of the current through the bulb.

Advantages. This type of test measures a pupil's ability to visualize things studied in the science program. Some pupils are better able to express themselves by drawing than by writing.

Disadvantages. Some pupils cannot make an acceptable drawing even when they can visualize an object. Such a test item should be given as a choice so that these last pupils may choose some other form of expression. Generally, drawings require a disproportionate amount of testing time for completion.

Completion drawings. Pupils are given a drawing that is incomplete and they are asked to add the proper lines to complete the drawing.

Example 1. An electric bell, a push button, and a dry cell are pictured on the question sheet. Accompanying directions read, "Draw lines to represent the wires needed for making the bell ring when the button is pushed."
Example 2. The question sheet shows an outline drawing of a goldfish without fins. The directions read, "On this diagram of a fish draw the missing fins."

Advantages. This type of test requires less skill than a standard drawing test. Time needed for completion is short. The answers are usually simple to correct.

Disadvantages. Pupils may misinterpret the diagrams provided for them. Pupils need practice with completing the same types of drawings.

Essay questions. These well-known questions require a pupil to describe in words, usually organized in paragraph form but sometimes in outline form, his knowledge on specific topics. Sometimes the points he is to cover are outlined for him, sometimes he must anticipate what the teacher expects him to cover.

Example 1. Explain how a submarine is made to rise or sink.
Example 2. Describe the life cycle of the American toad, indicating where each stage is spent and the seasons when important changes occur.
Example 3. With the aid of diagrams explain why you can hear an echo.

Advantages. This type of test shows what goes on in a pupil's mind more clearly than other types of purely verbal tests. It indicates how orderly his thinking is and how good his grasp of fundamentals. Essay test items should be included in most tests.

Disadvantages. Some pupils cannot express themselves well in written language and are penalized unduly. They may be discouraged if faced with too many essay questions. Though essay questions are easy to formulate, they are burdensome to grade and few can be used in any one test without imposing a hardship.

Short explanation questions. This type of question is but a shortened version of a standard essay question, the subject being limited so that the answer may be given in a single sentence.

Example 1. Explain with one sentence the following statements: (1) The lowest string of a violin has a larger diameter than the highest string. (2) A trombone player lengthens his horn to play a low note.

Advantages. This type of question tests a pupil's understandings in the same fashion as an essay question but is more economical of time for both the pupil and the teacher. By using several of these instead of a single essay question, a greater coverage of material is possible.

Disadvantages. Some pupils cannot express themselves well even with single sentences and many have difficulty in writing concisely enough to give an answer in so limited a fashion.

Completion statements. Pupils are given a set of statements that lack a word or phrase for meaning. The pupil is supposed to add a word or phrase in the blanks provided, either within the sentence or at the side.

Example 1. Fill in the blank in each of the following with the proper word:
(1) An explosive gas that is lighter than air is ________.
(2) The product resulting from the combustion of sulfur and oxygen is ________.

Example 2. Write in the space in the left-hand margin the word that best completes the following sentences:
________ (1) The part of the automobile engine where air and gasoline vapor are mixed is the ___(1)___.

Advantages. These tests measure how well pupils can recall words or phrases, and when recall is important they make an excellent testing device, easy to take and relatively easy to score. Wide coverage is possible in a short time.

Disadvantages. The test does not measure understandings, only recall of words. It cannot be scored mechanically; the teacher must be alert for the possible significance of each separate answer.

Multiple choice. A multiple choice test is somewhat like a completion test in that statements are not completed. Several possible suggestions are given and the pupil is to choose one or more from them. It stresses recognition rather than recall.

Example 1. Underline the word that best completes each of the following statements:

(1) The alloy of copper and tin is called (solder, zinc, bronze, brass).

Example 2. Write in the spaces at the left the number of the word that best completes each of the following:

——— 1. The portion of the sun's spectrum that causes sunburn is (1) infrared (2) yellow (3) ultraviolet (4) Hertzian (5) orange.

Example 3. Underline the words that may be used to complete the following statements correctly. More than one word may be suitable.

1. Air is (colorless, elastic, weightless).
2. One of the gases in the atmosphere is (argon, nitrogen, oxygen, carbon dioxide).

Advantages. Multiple choice items can be answered and scored rapidly. A wide range of subject matter can be tested in a short time. The questions are fairly easy to write. By using four or five alternates in each question, the effect of guessing is relatively unimportant. These tests are excellent for all purposes, motivation, review, and evaluation.

Disadvantages. These questions measure only on the recognition level. Because the scoring is mechanical, there is danger that the problems of the pupils will be overlooked.

Correction tests. Pupils are given sentences or paragraphs with a number of italicized words which reduce the meaning of the statements to absurdity. Pupils are to replace the italicized words with others which make the statements intelligent.

Example 1. Change the italicized words in the following paragraph so that the paragraph has meaning:

Tom went down to the *garden* to go fishing. The trout were swimming about with their *hands* and *feet* looking for *chickadees* and other insects. Tom baited his hook with a *carrot* and tried to catch one of the trout.

Advantages. This type of test is a welcome variant to standard tests and pupils like its absurdities. It measures recall in the fashion of completion tests.

Disadvantages. This type of exercise has the same disadvantages as completion tests with the added problem that the wrong words may distract the thinking of the pupils. Perhaps it should not be used for determining grades.

Matching exercises. The question sheets for this type of test list two parallel columns of words or phrases. Often there are more items in one column than in the other. Pupils are asked to pair the words in the two columns and indicate their decisions by writing letters or numbers in appropriate blanks.

Example 1. Choose from the list at the right the word that seems most closely related to each of the words in the left hand column. Write the numbers of the words in the corresponding blanks.

______ refraction	1. mirror
______ light source	2. lens
______ absorption	3. incandescent wire
______ reflection	4. black cloth
______ light transmission	5. vacuum
	6. night

Example 2. Below are some scientific principles, each of which has been given a letter. At the left are some devices that operate because of these principles. Write the letter given to a principle in the blank by the device that operates on this principle. You may use each more than once.

______ thermostat	A. Cold air is heavier than hot air.
______ thermometer	B. Most liquids expand when heated.
______ hot air furnace	C. Different metals expand at different rates when heated.

Advantages. This type of test is quickly answered if the number of items is limited to ten or so. The answers are quickly checked. The range of material tested may be broad. Guessing is reduced, especially if one column contains more items than the other.

Disadvantages. Too many items become confusing. There is always a strong possibility that two or more associations can be made for any item; mechanical scoring does not reveal the thinking of the pupil. Pupils should be given opportunities to explain their choices.

Grouping tests. This type of test requires pupils to recognize several terms that are associated with each other. In a list of several items the pupils are to select those that are related in some way and to discard those that are not.

Example 1. Below are sets of five terms, only four of which are related in some way. Cross out the word that does not seem to belong with the others:

cow duck horse rabbit cat
oriole robin chickadee tanager bat.

Example 2. Below are sets of five terms and a suggestion for the way four of the terms are related. Cross out the term that does not belong with the others:

hygrometer, barometer, anemometer, ammeter, thermometer (weather instruments)
hurricane, cyclone, typhoon, monsoon, isobar (type of wind).

Advantages. This is an interesting type of test and it stimulates discussion. It tests knowledge of groupings.

Disadvantages. Alternative groupings may suggest themselves to pupils unless suggestions are given.

Arrangement exercises. The pupils are given a list of terms that are to be arranged in some specified order.

Example 1. Following are the names of the planets. List these in order of their distance from the sun, beginning with the nearest:

Mars	Earth	Uranus
Pluto	Saturn	Jupiter
Mercury	Neptune	Venus

Example 2. Below are the names of the processes used in preparing a photographic print. List these in the order in which they occur:

fixing	washing	stop bath
exposure	development	drying

Example 3. Below are drawings of the four stages of the housefly. Put a number 1 by the first stage, a 2 by the second stage, and so on.

Advantages. This type tests knowledge of sequence and order. It is good for review and for starting discussions.

Disadvantages. It is difficult to give partial credit in scoring this test. Probably it should not be used in determining grades.

True-false items. In this familiar type of test, pupils are given a number of statements which they are to judge for accuracy. They may accept a statement or refuse to accept it signifying their decisions with *true* or *false*, *yes* or *no*, or a plus or minus sign. Sometimes a pupil is permitted to qualify his answer with a sentence telling why he cannot answer either way.

Example 1. Write the word *true* or *false* in the blanks at the left of each statement:

__________ 1. White pines have five needles in each cluster.

Example 2. Circle the letter T at the left if you believe a statement to be true. Circle the letter F if you believe it to be false.

T F 1. A ship will sink deeper as it passes from the Hudson River into the Atlantic Ocean.

Example 3. In the space at the left of each statement, make a plus sign if you believe the statement to be true. Make a minus sign if you believe it to be false. If you do not believe the statement can be called either *true* or *false*, make a zero in the blank and explain your reason below.

______ 1. Ice must change to water before it can change to a vapor.

Advantages. A great number of items can be answered in a short time, making broad coverage possible. The answers can also be checked rapidly, particularly with the use of a key. This type of test is good for initiating discussions and makes a good pretest.

Disadvantages. It is very difficult to write items that are strictly true or false without qualifying them in such a way that pupils can guess what is expected of them. Much of the material which lends itself to this type of testing is relatively unimportant in the science program. If pupils guess the answers, they have a one to one chance of selecting the right answer. Mechanical grading makes it impossible to know why a pupil made his choice. True-false items are not well suited for determining grades.

Modified true-false items. True-false tests may be modified to reduce the guessing prevalent in standard true-false tests and to encourage a higher degree of thinking. The statements made are the same but pupils are to rewrite false statements so that they are true. Usually some clue as to the desired change must be given.

Example 1. If you judge the statements below to be true, write *true* in the spaces at the left. If you judge them to be false, rewrite them so that they are true.

______ 1. Chlorine added to drinking water removes dissolved minerals.

Example 2. Below are some statements, some of which are true and some of which are false. If you believe a statement is false, change the italicized word so that the statement is true.

______ 1. Butterflies have *four* wings.

______ 2. Houseflies have *four* wings.

Advantages. This modification of a true-false test is useful in stimulating discussion.

Disadvantages. The time needed for checking the answers is increased and it is difficult for pupils to score them. It is also difficult to assign credits for giving grades.

Sometimes—always—never items. This type of test is much like a true-false test with a third alternative offered.

Example 1. If you believe one of the statements below to be always true, circle the letter A at its left. If you believe it is never true, circle the letter N. If you believe that it may sometimes be true, circle the letter S.

A S N 1. A magnet has two poles.
A S N 2. An electric current sets up a magnetic field.
A S N 3. Like magnetic poles attract each other.

Advantages. The addition of the third alternative reduces the chances for guessing to one in three. The test is speedily answered and scored. The questions may stimulate a good deal of discussion while being scored.

Disadvantages. When writing the items it is difficult to avoid giving clues to the answers expected. The fairly high chances for guessing correctly reduce the value of these items for giving grades.

TEST CONSTRUCTION

Test construction is the most critical phase of the testing program. A number of factors must be considered: the function of the test, the type of learning to be tested, the way the test is to be administered, and the way it is to be scored. A number of decisions must be reached before actual writing begins.

Techniques for testing easily verbalized factual information are highly developed; these may be used with assurance. Performance tests for determining degrees of manipulative skills are also reliable. Less can be said for the procedures that have been developed for measuring the broad outcomes of science—the skills used in applying principles to new situations and the ability to think critically, and to discriminate. Statistical analysis of the results from these last tests shows that unwanted factors often enter and invalidate the results.

The problem is that these broad outcomes are not verbal; they determine courses of action and the only real way to measure them is to see how an individual reacts in a specific situation. He must not even know that he is being tested, because that knowledge will condition his behavior.

Verbal tests designed to measure broad outcomes commonly describe hypothetical situations and ask pupils to make decisions or describe courses of action they might follow. Pupils are conscious of being tested, of course; they may take added time for reflection, they may be influenced by the wording of the question or a list of alternatives from which to choose, and their answers may be completely unrealistic.

The verbal factor enters immediately. A special premium is given for ability to visualize from the printed page and to express thoughts

in writing. The final score on the test reflects reading and writing ability in an undetermined amount. Another factor, insight, enters this type of testing. Pupils with insight can make proper choices with a minimum of background. Thus a test may measure intelligence as well as achievement and the final score is affected by both.

It is recommended here that beginning teachers be cautious about using tests of broad outcomes in the determination of grades lest injustices occur. However, this statement should not blind teachers to the high value of these tests in promoting discussions and stimulating special problems.

Preliminary decisions. The type of test item used in measuring factual information will be determined by the level of learning expected. It would be unfair to ask questions that demand mastery when the topic tested was treated casually in the classroom. Essay questions are best for determining mastery. Completion items may be used for the recall level. Various association exercises may be used for the recognition level.

The range of the sampling desired influences the choice of test items. Little sampling is possible with essay questions or other questions that require a relatively long time for completion. Short-answer test items permit broad coverage in the time allotted.

Problems of scoring must be considered. If a teacher must give long tests to a large number of pupils he should use test items that are scored quickly. If pupils are to score the tests only items that call for positive answers should be employed so that the teacher need not determine the validity of the many alternative answers that may be given.

For major tests it is usually wise to include several different types of test items. Variety makes taking a test more pleasurable and reduces the fatigue factor in both taking and scoring. Variety also permits the display of a greater variety of pupil talents; in a series of short tests this objective can be met by using a different type of item for each test.

When tests are to be used for grading, items that permit simple scoring are preferred. Test items that require weighted scores for different types of answers, such as modified true-false, or correction factors to compensate for guessing, are too cumbersome to be practical.

Writing test items. The best questions are always simple and direct. Each additional adjective, adverb, and qualifying clause increases the complexity of a question and augments the possibilities for misinterpretation. Words should be those commonly used in the classroom; the mere introduction of a new word in a lesson does not justify its use in a test unless it was used again and again so as to become part of the

pupils' vocabulary. There is always danger that verbal tests may become little more than vocabulary tests. Questions should be written to measure understandings rather than the ability to use words.

Precision of writing is essential. Essay questions are particularly apt to be vague. Instead of asking pupils to describe the life history of the honey bee, the question should specify precisely what is wanted:

> Describe the life history of the honey bee, telling what stages it passes through, where the eggs are laid, how the young are cared for, and how the queen differs from the other females in the colony.

Short answer questions that allow but one correct answer need especially precise writing. It is not uncommon to find two or more of the choices correct even though only one is accepted. In a matching exercise, the word "inorganic" in the right hand column could be matched correctly with nine of the ten words in the left hand column. A multiple choice item on a final examination read:

> Water in the atmosphere exists as a (1) solid (2) liquid (3) gas.

Completion questions are especially difficult to write because even slightly different interpretations of the questions may bring to mind a wide range of answers. The following question illustrates the point:

> Green plants produce their own __________.

A pupil who thinks in terms of photosynthesis may write "food," "sugar," "carbohydrates," or some equivalent word. All would be correct. A pupil who thinks along a different channel might answer "chlorophyl," "cellulose," "leaves," or even "oxygen." These answers are not all equally valid but they do not represent errors of thinking and should be accepted because the question itself is at fault. The above question should be rewritten to help pupils understand more precisely what answer is desired of them:

> Green plants can produce their own food only in parts that contain __________.

Broad generalizations are particularly difficult to test. Frequently even the test maker does not have sufficient background to recognize the limitations of a generalization. The following item has been encountered several times:

> Magnets have (1) one pole (2) two poles (3) three poles (4) four poles.

Undoubtedly, the test makers have expected the second choice to be the only correct choice. They have not realized that magnets with more than two poles do exist. They would not have fallen into error,

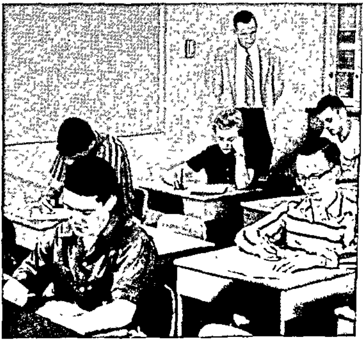
however, had they written the question so that it dealt with a specific case:

> *Our bar magnets have* (1) *one pole* (2) *two poles* (3) *three poles* (4) four poles.

Weaknesses of the types just illustrated are not serious in tests used for motivation, review, drill and the like. Indeed the variations in answers can give rise to very interesting discussions and additional study. But it is most unfair to include such questions in tests which are used for determining grades.

TESTING PROCEDURES

Administering tests. Generally the most favorable time to give a test is at the beginning of the period. During the interval between classes the pupils have had opportunities to move about and relax. They are in the best condition to sit in quiet concentration for a few minutes. Should it be essential that the test be given later in the period, it may be wise to let the pupils stand, stretch, and otherwise release physical



Test administration needs the same careful planning as do all other phases of a lesson. A teacher should devise efficient methods for giving out and taking up test papers. He should try to anticipate all points that might cause confusion. He should discourage cheating by arranging for dispersed seating and by supervising the test from a good vantage point at the rear of the room.

tensions. Should the test be given at the end of the period, it should be timed carefully so that all pupils complete it before the class bell rings.

It is difficult for pupils to sit quietly and concentrate when they are excited about athletic contests, social events, and holidays. Tests used at these times should be short. The scores may not be valid and should rarely be used in determining final grades.

Physical conditions under which tests are to be taken deserve consideration. Lighting should be adequate and shades should be drawn if sunlight falls on the pupils' work. The temperature should be comfortable and the air fresh. It is sometimes desirable to ventilate a room thoroughly before a test, this being preferable to trying to adjust windows during the test.

The manner in which a test is introduced may greatly influence the attitude of the pupils. An efficient, business-like manner, with directions given crisply and clearly, makes the test seem important. A calm, unhurried attitude relaxes the pupils without minimizing the importance of the task.

The shortest possible interval between the announcement of a test and the beginning of work helps keep the attention of the pupils centered on the task. Pupils should clear their desks and have their pencils ready. If duplicated question sheets are used, these should be divided and passed back by rows. If the questions have been written on the blackboard, these may have been covered by charts which are quickly removed. As soon as each pupil is ready, directions for answering the test should be given tersely but adequately.

Interruptions should be kept at a minimum. Errors in the question sheets may be discovered by reading the test in advance of the class period; corrections may be dictated at the same time directions are given. Pupils who are puzzled by illegibility, unfamiliar words, and possible multiple interpretations may be helped in individual consultation rather than by loud-voiced questions that distract others.

Cheating is much more prevalent than many teachers realize. It is a serious problem. It is unfair to those who do not cheat. It handicaps those who cheat by depriving them of a chance to recognize their own strengths and weaknesses. It contributes to the moral degeneration of young people.

Cheating can be reduced by improving the emotional atmosphere of the classroom. Tensions tend to build up when a great deal depends upon the outcome of a test. Pupils cheat to protect themselves against the penalties that may result from failure. The use of frequent practice tests gives pupils a feeling of competence. Determination of grades

by the use of many measures, including many tests, reduces the importance of any one test.

Cheating can be discouraged by establishing conditions that make it difficult. Opportunities for cheating are minimized if the pupils are well separated from one another and if their desks are cleared of books and papers. For major tests, it may be desirable to prepare for alternate rows two forms of a test, possibly with the same questions but in scrambled order.

Cheating is reduced if the teacher is obviously alert to the problem. He should move quietly about the rear of the room, watching the pupils casually. If he reads at his desk, or writes on the blackboard, or leaves the room, he is encouraging his pupils to cheat.

The conclusion of a short test does not usually present any serious problems because most pupils complete their work within a minute or two of each other. The variation in working time is greater for long tests and activities must be provided for those who complete their task first. These pupils may begin work on assignments, or do independent reading, or work on individual projects. Directions for beginning general assignments may be given at the time directions for the tests are given. Specific assignments may be given as each pupil turns in his test paper.

Checking and scoring tests. Pupils gain the greatest benefits from testing when they check their answers immediately after taking a test. At that time they can best recall the thinking that led them to make certain decisions. Whenever possible, pupils should be allowed to score their own tests, either as a group, with the teacher serving as the authority, or as an individual assignment, with texts and notebooks serving as authorities.

From an administrative standpoint the best types of tests for pupil scoring are those which call for single, positive answers, such as multiple-choice items and matching exercises. If a test permits alternative answers, as in the case of most completion questions and essay questions, the teacher is forced to judge each answer that differs from the one he dictates. This is time consuming and quickly becomes boring to a large number of the pupils.

Teachers should plan to score all tests used for determining grades. Grades become permanent records as to the successes and failures of pupils. Pupils cannot be trusted with this important aspect of teaching. They are not experienced in objective evaluation and they lack sufficient background to recognize exceptions and fine distinctions. And some are tempted to cheat because of a feeling of insecurity.

The task of scoring a large number of test papers can be most bur-

densome. Teachers should be alert for ways of simplifying the task. Often a few minutes spent in properly organizing a set of test questions can save an hour or more of scoring time.

Essay questions are especially fatiguing to look over. A teacher's objectivity deteriorates after reading through several dozens of answers. To reduce the fatigue factor it is wise to include single essay questions along with short-answer questions in a number of tests rather than to construct a few tests of essay questions only.

To improve objectivity in scoring essay questions, it is helpful to prepare a check-list of points expected in the discussion. A teacher should use a check list with discretion, however, remembering that pupils may not think of all the points that a teacher would desire even though they could discuss them adequately had these points been brought to their attention.

Short answer tests can be scored quickly through the use of keys. The process is simplified if the pupils are asked to write their answers in blanks along the left-hand margin of the question sheet. A matching exercise and the key used to score it is shown below.

A KEY USED FOR RAPID GRADING OF A MATCHING EXERCISE

Key	Answers	*Matching exercise*	
2	4	bituminous coal	1. abrasives
3	10	chalcopyrite	2. coke
6	6	galena	3. copper
1	1	garnet	4. gasoline
7	7	gypsum	5. iron
8	8	limestone	6. lead
5	5	magnetite	7. plaster of Paris
4	4	petroleum	8. Portland cement
9	11	pitchblende	9. radium
11	9	sphalerite	10. sulfur
			11. zinc

Another method which reduces the time for scoring is the use of a key placed over the answer sheet in such a fashion that correct answers can be observed through holes in the key. A set of numbers or letters is provided for each question on the sheet. The pupils are directed to block out the symbol which corresponds to the correct choice given in the question. The key is made by cutting out the

correct symbols in an extra question sheet. Figure 11 shows part of an answer sheet and key used in this fashion.

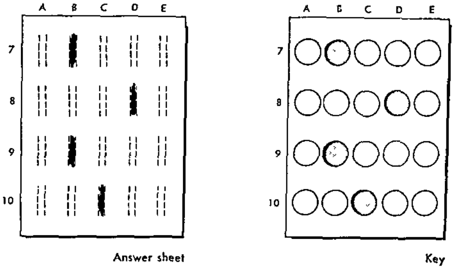


FIGURE 11. *A portion of an answer sheet from a multiple choice test, correctly answered, and its key. The key is prepared by cutting out the correct choices from a blank test paper. When the key is placed over the answer sheet, a pupil's correct answers show through the holes in the key.*

A device useful for rapid scoring of multiple-choice items is the arrangement of the correct answers in an easily memorized sequence such as 3, 2, 4, 1, 3, 2, 4, 1, and so on. Or the sequence may shift regularly—1, 2, 3, 4, 2, 2, 3, 4, 3, 2, 3, 4, and so on. The answers for the test given on page 290 are arranged in this fashion.

The dangers of mechanical grading must be emphasized. The individual and his ways of thinking are completely ignored. Proper analysis of tests, as described in the next section, will help identify exceptional ways of thinking and weaknesses of testing procedures.

There is no set rule that determines the amount of credit to be allotted to correct answers to the different types of questions. Teachers must rely upon their own judgment. Generally, more credit is allotted to those questions that require the higher degree of thinking. Thus a multiple-choice item might be given one credit, a completion question might be given two credits, a one-sentence answer five credits, and a one-paragraph answer ten credits.

When true-false and other either-or questions are used, the guessing factor ought to be considered. Theoretically, a pupil can achieve about half credit without even reading the questions and any knowledge, however slight, should raise him above this level. Obviously a correct choice should not be given the same relative weight as a multiple-

choice item, for instance. There are factors that can be applied to reduce the weight of these items but these are complex and it is simpler not to use such questions on tests used for final grades.

Teachers customarily assign credits in ten's to simplify the calculation of test grades in percentages. This is not necessary or always desirable. A test might be made up as follows:

12 multiple choice items at 1 credit each	12
4 completion items at 2 credits each	8
1 one-sentence answer question at 5 credits	5
Total	25

The final percentage grade may be calculated by multiplying the point score by 4. Thus, a paper with 20 points credit would be given a grade of 80%.

Some teachers prefer to use letter grades, especially for essay questions. It is then necessary to convert number grades gained on short-answer tests. One method commonly used to do this is to give an A for grades between 90% and 100% inclusive, a B for grades between 80% and 89% inclusive, and so on.

Some teachers prefer to record point scores rather than percent or letter grades. This procedure has the advantage of permitting the use of tests of different lengths without providing factors to insure proper relative weights. However, pupils may not understand the significance of a point score and it may be wise to convert these to percentages on the papers before returning them.

The effort to be objective in grading is apt to result in some overly rigid practices. There are, however, several ways to provide flexibility without being influenced appreciably by prejudice. One may give pupils a choice of several questions, say ten out of twelve questions. This procedure assumes that none of the material of the test is essential and that pupils should be credited for mastering any substantial portion of it.

It is also possible to grade a test on the basis of fewer questions than are actually asked. For instance, a test may be made up of 44 items but the grade would be calculated on the basis of 40 questions. This practice presupposes that it is natural and not serious for pupils to make some mistakes.

Some teachers like to add bonus questions for pupils to answer if they have time and inclination. Credits earned from the bonus questions are added to the basic score. This procedure awards pupils for additional effort in the course. Teachers may also give as bonus points more credit than is generally assigned to a question when the answer is unusually good. This practice rewards pupils for extra insight.

Some of the above methods make possible percentage scores over a hundred. When point scores are used, this is immaterial. Special explanations might be in order should outsiders investigate the grading system.

Analyzing test results. After a test has been scored it is usually worthwhile to spend a few minutes in analysis of the results. An analysis may reveal deficiencies in teaching and faulty test constructions that would go unsuspected otherwise. Sometimes it is discovered that pupils are penalized for the faults of the teacher.

Short answer tests are easy to analyze. A test given to twenty-eight ninth grade pupils is shown on page 290. The grades attained by the pupils tell little save that about half the class did rather poorly. There is no clue as to whether the fault lies with the pupils, the teacher, or the test. An analysis may help identify the difficulties.

The first step is to total the number of correct answers for each item. These are written in the blanks on an unused paper as shown in the sample. Immediately it can be seen that items 1, 2, 4, 7, and 8 gave little difficulty to any pupils. Quick review of the questions shows that the material is not simple and the alternate choices are not ridiculous. It may be assumed that the material tested by these items is well taught.

The other items, particularly number 9, are unsatisfactory and need further investigation. The papers are now sorted into two equal piles with the higher scores in one pile and the lower scores in the other. The distribution of correct answers in each pile is now determined for each item. The information is then entered on the test sheet.

In the case of item 3, twelve of the high scoring pupils gave correct answers but only 2 of the low scoring pupils were able to do so. Random guessing might account for the latter two. It would seem likely that this is a difficult question and examination of the wording reveals that it is. It is difficult for many pupils to believe that carbon, which they know as a black solid, can exist in the air. The distribution of their choices shows that they selected soil or fertilizer as the logical source for a black solid. It is probable that this information was treated on an abstract plane and only certain pupils could grasp the concept. The fault lies almost certainly in the teaching.

Thirteen of the high scoring pupils answered 5 correctly. No pupils selected the rose as a choice, a fact that indicates some understanding of the nature of the rose plant. Wrong choices were distributed between mosses and ferns and probably some pupils guessed mushrooms correctly. It seems that the pupils have little understanding of these three plants. They need extensive experiences with them.

TABLE 13. A NINTH GRADE SCIENCE TEST AND DATA USED TO ANALYZE IT *

Name *28 pupils* Score ________

Choose the word or phrase you think best completes the following sentences. Write the number of the word or phrase in the blanks at the left.

28 1. Plants that make their own food must contain (1) acids (2) bases (3) peptones (4) chlorophyl.

26 2. Energy needed by green plants for food manufacture comes from (1) light (2) fats (3) fuel (4) air.

14 / *12-2* 3. The carbon needed for the sugar produced by plants comes from (1) water (2) the soil (3) the air (4) fertilizer.
2 5 14 7

28 4. During food manufacture, a plant gives off (1) proteins (2) oxygen (3) carbon dioxide (4) alcohol.

21 / *13-8* 5. An example of a plant that cannot make its own food is the (1) rose (2) moss (3) mushroom (4) fern.
0 4 21 3

12 / *8-4* 6. Much of the food produced in a green plant is stored as (1) starch (2) wood (3) cellulose (4) vitamins.
12 6 10 0

26 7. Trees manufacture most of their food in their (1) roots (2) stems (3) leaves (4) bark.

27 8. The manufacture of food by green plants is called (1) osmosis (2) photosynthesis (3) chloroplasts (4) solution.

8 / *4-4* 9. Hydrogen needed by plants for the manufacture of food comes from (1) the soil (2) water (3) air (4) acids.
5 8 12 3

18 / *12-6* 10. Food manufactured by plants is used chiefly for (1) growth
18
(2) keeping warm (3) enriching the soil (4) inorganic
1 5 4
compounds.

16 / *11-5* 11. Most cactus plants manufacture food in their (1) roots
0
(2) leaves (3) stems (4) flowers.
12 16 0

20 / *8-12* 12. Parasitic plants get their food from (1) the soil (2) other
2
plants (3) animals (4) the air.
20 6 0

Distribution of Grades:

100 — 1	67 — 9
92 — 3	58 — 4
83 — 3	50 — 1
75 — 7	

* The significance of the italic number is given in the text.

Skipping to item 11, it seems that almost half the class, assuming some guessed correctly, had little knowledge of the structure of cactuses. Probably this subject was touched upon in class without the use of specific examples so that only pupils with good experience backgrounds or the ability to visualize from words grasped the desired concept.

The answers for item 10 show about the same distribution as those for item 5. It is surprising that more pupils did not answer this one correctly. Some of them must have been confused by the question or by something said in class. Perhaps the correct alternative looked too simple when compared with the last two. Many pupils who do not feel secure in academic work do not trust their own knowledge in tests.

Item 6 would be a confusing question if class discussion had centered about trees, because certainly a large amount of a tree's food is converted to wood and cellulose. Perhaps that is what happened in this case. Again the distribution of scores indicates that it was a difficult question.

Item 9 shows such a low total that the correct answers could be attributed to random guessing. It seems likely that this topic received no attention in class work, perhaps due to an oversight. It, like item 3, is a very difficult one to deal with and pupils need many concrete experiences to make the concept meaningful.

The distribution of scores for item 12 opposes the pattern shown for most of the other items. In this instance more of the low ranking pupils answered the question correctly than did the high ranking pupils. The effect of random guessing cannot be ignored but it seems likely that the test item itself is at fault. Critical inspection of the alternate choices reveals that the third alternative is correct. Perhaps some of the higher ranking pupils had information that led them to make this choice.

In summary, the analysis shows that about 40 percent of the material covered by the test was well taught. Of the remainder, most had been well taught on an abstract level but about half the pupils needed more concrete experiences—experiments, demonstrations, and the like. One topic seemed to have been ignored during classwork. One test item was faulty and should have been discarded when the teacher calculated scores.

Similar analyses may be carried out for all test results. When working with essay tests and performance tests, it is necessary to break down each question into its component parts to calculate the distribution of correct answers. One must not expect to understand all the situations revealed by an analysis, but the analysis will point out many things that normally go unsuspected.

STANDARDIZED ACHIEVEMENT TESTS

Inevitably, during the testing program, the question arises, "How does this group of pupils compare with pupils elsewhere?" To make comparisons many tests have been constructed for use on a system-wide, a county-wide or a state-wide basis.

Such tests constructed by amateurs are apt to be unfair to pupils because of mechanical faults—poorly worded questions, "tricky" alternatives in multiple choice items, and the like—faults that can be discovered only by expensive statistical analysis. In consequence, there has been a demand for tests constructed by commercial testing bureaus which have the facilities for proper analysis. These tests are standardized for nation-wide usage and supposedly represent the best in test making.

Standardized tests have been constructed for each of the major subject matter areas. For science, there are batteries of tests to measure general achievement in science as well as tests for the special branches. There are also tests that are claimed to measure scientific aptitude.

Uses of standardized tests. Standardized achievement tests are best adapted for diagnostic purposes. In the science program they may be used as follows:

1. *To determine the achievement level of individual pupils.* This information is helpful in assigning a pupil to a grade or section, and to determine his fitness for an advanced course.

2. *To determine a pupil's areas of strengths and weaknesses.* A battery of achievement tests reveals the areas in which a pupil has achieved more or less than that which is normal for others of his age and grade. The information helps in guiding him into special fields or in planning remedial work.

3. *To determine a pupil's progress.* Two forms of the same test, given a few months apart, indicate growth during the interval. Abnormal growth, whether unusually rapid or slow, draws attention to his need for special consideration.

4. *To determine the relative standing of a class as a whole.* This information helps in program building. A class that scores much higher than the national norm can probably do more advanced work than a class at or below the norm.

5. *To determine areas of strength and weakness for a class.* During the planning of a balanced program it is helpful to know which areas need special emphasis.

6. *To determine class progress.* Progress as measured by achieve-

ment tests is one measure of the effectiveness of the teaching procedures being used.

Limitations of standardized tests. Scores attained on standardized tests should not be used as sole determiners in making up final grades; it may be that they should not enter into the grading process at all save to reveal pupils who are being penalized unfairly by the testing techniques used. Standardized tests cannot fit the local curriculum. They cannot measure most of the desirable outcomes of a program.

Standardized tests are sometimes misused. Too much is expected of them. Their misuse can be traced to the fallacious assumption that there is a certain body of information that pupils should acquire by regular yearly increments. This presupposes that there is a universal curriculum, which is contrary to present-day educational philosophy.

> Teachers and administrators sometimes make the mistake of assuming that the total effectiveness of the learning situation can be measured by standardization tests. If this kind of thinking prevails, the results of the achievement test become identified as the main objective. Instead of a curriculum being a growing thing, changing from time to time to meet the needs of students and the community and responding to the individual talents of the members of the teaching staff, it becomes stereotyped and even sterile. The chief end of teaching, under such circumstances, is the preparation of students to pass the achievement test. Thus teachers are prevented from attempting to make any improvements in the curriculum, because they are afraid that any deviation, no matter how slight or how desirable, may result in students making lower marks on the examination.[1]

The weaknesses of standardized tests do not make them useless; they only limit their usefulness. Standardized tests are among the many educational tools needed to insure maximum benefit for the boys and girls in our schools.

Suggested activities

1. Make up several samples of different kinds of test items. Submit these to your science methods class for criticism.
2. Study the test items given in a text book or other publication, examining them for possible weaknesses that might confuse pupils.
3. Obtain a set of answer papers from a science teacher and analyze the scores to look for weaknesses in test construction.
4. Prepare a pencil-and-paper test for a science class, administer it, and analyze the results.
5. Set up a test that uses actual materials and administer it to a science class.

[1] Lindgren, H. C., *Educational Psychology in the Classroom*, Wiley, New York, 1956.

6 Examine standardized tests in science or the science section of general achievement tests. Try to determine how well the tests meet their objective.

7 Start a test item file.

Suggested readings

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Part III

Plans and Planning

Planning is more than a listing of topics to be covered. Planning provides for what the pupils will be doing at all times. It takes into account the special talents and interests of each pupil. At best, planning is a process shared between teacher and pupils.

SETTING OBJECTIVES FOR SCIENCE TEACHING

chapter 12

Why do pupils come into *one classroom with a sense of anticipation and into another with* indifference or even distaste? Why does one group of pupils find class periods all too short for what they want to do while another group never thinks of working voluntarily after school or at home? Why is it that two teachers can follow the same course of study and give the same examinations but provide such different atmospheres for their classrooms?

The difference between teachers can often be traced to the objectives which they set for themselves. The teacher whose primary objective is "*getting through the textbook by June*" inspires no one. *But* the teacher who sincerely wishes to further the over-all growth of his pupils has a lasting influence upon them.

The most successful teachers have broad objectives. A physics teacher with a truly remarkable record each year trains a team of young people to speak on science topics to service clubs and other organizations; he considers such training to be among his many responsibilities. An excellent biology teacher takes pupils so thoroughly into the planning process that they can carry on for long intervals without his presence in the classroom; he believes that acceptance of responsibility is an important outcome of his program.

Several broad objectives tend to reinforce each other whereas a single narrow objective in is danger of defeating itself. The teacher who is concerned only with the mastery of information is apt to deny his pupils opportunities to do things they consider important; they be-

come apathetic; he becomes harsh and dour; conditions spiral toward failure. But the teacher with broad objectives wants his pupils to do things they consider important; they respond with enthusiasm and effort; their effort brings success and success spurs them to further efforts; conditions spiral toward eventual attainment of objectives.

SUBJECT MATTER OBJECTIVES

In the final analysis, all objectives for the science program should be determined by the needs of young people. Their needs fall into two categories: (1) those that can be satisfied by acquiring information and special skills, and (2) those that can be satisfied by developing certain ways of thinking and acting. The former are called "subject matter objectives." The latter are sometimes called "general education objectives" because they govern the entire school program irrespective of subject matter divisions.

These two sets of objectives operate in close conjunction with each other. Each set has its special influence upon the program. Subject matter objectives determine the content of the program. General education objectives determine what is done with the content. Neither set is effective without the other.

Long and short range subject matter objectives. Pupils can learn through a single experience that a magnet can pick up bits of cobalt. They need dozens of experiences to realize that water is a poor conductor of heat. They need thousands of experiences to appreciate the statement "All life comes from life."

An objective calling for the learning of the magnetic properties of cobalt can be attained in a relatively short time, perhaps a few minutes. Objectives of this type, which may be called "short range objectives," are used to govern field trips, experiments and other limited activities. Two or three short range activities may be established for a single lesson.

Other subject matter objectives are so broad that some of them cannot be considered truly attained at the end of a year's program or even after twelve years of schooling. These long range objectives should be treated as aims that give direction to a program rather than as goals for rapid attainment.

In a well organized program, short range objectives are set up so that they lead towards long range objectives. A number of experiments with pulleys, each directed towards one specific objective, can, when properly related, bring about an understanding of pulleys in general.

Setting long range objectives. During the 1920's and 1930's a great deal of work was done on the formulation of major generalizations that could be used as long range objectives to give continuity to the science program. A list of thirty-eight such generalizations was published in the Thirty-first Yearbook of the National Society for the Study of Education.[1] This list is given on pages 300-301. Although these generalizations need minor modifications in the light of recent scientific discoveries, they still represent an excellent point of departure for the program maker.

This list was designed to give direction to the entire science program from grades one through twelve. One of its major strengths is the balance it provides among the traditional subject matter areas and the interrelationships it promotes between the areas. It represents a broad approach to the problems of planning.

Teachers of the specialized sciences have not always recognized the application of the entire list to their own subjects. They have admitted that broad courses such as elementary science and general science could be governed by a broad list of objectives, but for themselves they have tended to select only such generalizations as they considered pertinent. *By so doing they have perpetuated the narrowness* of their courses.

Specialized courses are bettered by having broad objectives. A physics teacher may show the application of principles governing balance to the human body, and the application of findings about heat transfer in water to the problems of organisms in ponds. By so doing he makes his course more significant to the wide range of pupils who would benefit by the study of physics.

The use of major generalizations as objectives for a unit may result in superficiality, if they are treated *as goals rather than as aims.* To avoid this danger it is wise to break up a major generalization into segments, each of which is limited enough to be attained by the experiences possible within a unit. A major generalization about machines, for instance, could be subdivided in terms of the types of machines, permitting separate units on levers, pulleys and so on, or in terms of such phases as efficiency, mechanical advantage, and so on, each of which could well merit a complete unit for proper treatment.

Sources of suggestions for long range objectives are (1) courses of study, (2) textbooks, (3) yearbooks. The beginning teacher will prefer in all probability to adopt a set that has already been formulated

[1] *A Program for the Teaching of Science*, Part I, Thirty-first Yearbook of the National Society for the Study of Education, Public School Publishing Co., Bloomington, Ill., 1932.

MAJOR SCIENCE GENERALIZATIONS

1. The sun is the chief source of energy for the earth.
2. Through interdependence of species and the struggle for existence, a balance tends to be maintained among the many forms of life.
3. The earth's position in relation to the sun and moon is a determining factor of life on earth.
4. All life comes from life and produces its own kind of living organism.
5. Matter and energy cannot be created or destroyed but may be changed from one form to another.
6. Species have survived because of adaptations and adjustments which have fitted them to the conditions under which they live.
7. The energy of solar radiation is continually working changes in the surface of the earth.
8. There have been profound changes in the climate, not only of certain regions, but also of the earth as a whole.
9. The evolution of the earth has come as a result of natural forces.
10. Units of time are defined by the earth's movements in relation to the sun.
11. All life has evolved from simple forms.
12. The earth seems very old when its age is measured in the ordinary units of time.
13. Distances in space seem extremely vast when compared with distances on the earth.
14. The physical environment has great influence on the structural forms of life and on plant and animal habitats.
15. Man can modify the nature of plant and animal forms through application of his knowledge of the laws of heredity.
16. There is a great variety in the size, structure, and habits of living things.
17. There are processes that go on within an organism that are vital to its continued existence.
18. Chemical and physical changes are manifestations of energy changes.

19. There are fewer than one hundred chemical elements.
20. Every substance is one of the following: (a) a chemical element, (b) a chemical compound, (c) a mechanical mixture.
21. Certain material substances and certain physical conditions are limiting factors to life.
22. Light is a limiting factor to life.
23. Sound is caused by waves which are produced by a vibrating body and which can affect the auditory nerves of the ear.
24. Gravitation is the attractive force that influences or governs the movements of astronomical bodies.
25. Machines are devices for accomplishing useful transformations of energy.
26. Any machine, no matter how complicated, may be analyzed into a few simple types.
27. The properties of the different elements depend on the number and arrangement of the electrons and protons contained in their atoms.
28. All matter is probably electrical in structure.
29. The applications of electricity and magnetism in the home and in industry have revolutionized the methods of living of many people.
30. Heredity determines the differences between parents and offspring, as well as the resemblances.
31. The kinetic energy of the molecules determines the physical state of matter.
32. The gravitational attraction between the earth and a mass of unconfined gas or liquid causes the pressure of the liquid or gas on the surface of the earth.
33. Liquid or gas pressure is exerted equally in all directions.
34. Chemical changes are accompanied by energy changes.
35. A change in rate or direction of motion of an object requires the application of an external force.
36. Radiant energy travels in straight lines through a uniform medium.
37. Electricity is a form of energy that results from disturbing the position of the regular paths of the electrons.
38. In a chemical change, a quantitative relationship exists between the amounts of substances reacting and the amounts of the substances that are products of the reaction.

for his specific courses but he may find it wise to check the breadth of these objectives and add others if the set seems too narrow in scope.

The teacher should always remember that long range objectives are not written for pupils to verbalize. Mere verbalization does not add to understanding but does give an impression of mastery. Many a teacher has ended prematurely his efforts at developing understandings because the statements of his pupils led him to believe that his objectives had been attained.

Setting short range objectives. Limited objectives used to govern demonstrations, reading assignments and other learning activities are usually expressed as specific learnings and skills:

Kingfishers and bank swallows nest in holes in sand banks.
Zinc displaces hydrogen from hydrochloric acid.

The former might be an objective for a field trip; the latter an objective for a laboratory experiment. The list below gives the specific learnings set up as objectives to be met in a unit on fire; each of these objectives may govern several activities:

1. A fire will not continue to burn in a closed space.
2. Solid and liquid fuels are frequently changed into gaseous form before combustion occurs.
3. In a luminous flame, combustion takes place where the combustible gases come in contact with air.
4. A proper mixture of combustible gas and air results in a nonluminous flame.
5. The amount of heat required to raise a combustible substance to its ignition point depends upon the nature of the substance, the amount of water present and other factors.
6. Combustion occurs more readily when the combustible substance is in a finely divided state.
7. Fires may often be started by means of friction.
8. Heat produced by slow oxidation can ignite some substances.
9. The substance in the air that supports combustion is called oxygen.
10. Fire is chemical union of oxygen with a combustible substance.
11. Fire may be extinguished by reducing the temperature or by removing the fuel or oxygen.

The more limited an objective the more likely that it can be attained within the allotted time and the less the danger of superficiality. The simpler the language in which it is expressed the more likely that the verbalizations of the pupils will approach the desired objective.

Various criteria may be used in the selection of short range objectives:

1. *Usefulness.* The desired learnings should have value in the lives of the pupils.

2. *Timeliness.* Learnings should be concerned with material familiar at the present time; not with obsolete devices and ideas.

3. *Fitness.* The learnings should fit into a sequence leading towards a long range objective.

4. *Appropriateness.* The learnings called for should be appropriate for the maturity and backgrounds of the pupils concerned.

5. *Practicality.* Experiences needed for the development of the learnings should be possible.

The third criterion is the one most frequently employed and is sometimes the only one employed, even to the exclusion of all general education objectives. Certainly the criterion is an important one, but overemphasis upon it may result in neglect of the learner.

The last criterion does not receive enough attention. Specific learnings are often set up as objectives without consideration for the means by which the learnings are to be obtained. The teacher may then find himself depending upon lectures and reading assignments when his pupils do not have adequate backgrounds to benefit from these.

A commonly used technique for the selection of specific subject matter objectives employs the developmental approach. A major generalization is written down and under it are listed the learnings that are considered essential for partial or complete understanding of the generalization. For example, referring to the generalizations for a unit on fire (page 302), the major generalization may have been written as "A fire is a chemical union of two or more substances" and the specific learnings as listed may have been considered as leading towards the generalization.

The specific learnings become tentative short range objectives subject to evaluation by the criteria listed above. A program based on these objectives is logically organized, its pattern is more or less traditional, and it is subject-matter centered. Much good teaching has been done with this type of program.

A second technique for establishing limited subject matter objectives is more opportunistic than deliberate. An area for study is first decided upon. Then a survey of pertinent learning situations is made. From these last a list of possible learnings is determined and set up as short range subject matter objectives:

Mr. Barker, when planning a unit on garden soils for his ninth grade general science class, listed as many suggestions for field work and experiments as his facilities permitted. These are given below.

Field trips:

1. Collect samples of soils
2. Observe top soil and subsoil

3. Test pH of soil in nearby gardens
4. Study compost heaps and humus
5. Visit garden store to study fertilizers

Experiments:

1. Test drainage of soils
2. Test capillarity of soils
3. Test water retention of soils
4. Experiment with effects of leaching
5. Discover effects of lime on soils
6. Test soils for structures produced in drying
7. Experiment with soil conditioners
8. Test effects of humus on soils
9. Experiment with growing plants in different soils
10. Experiment with effects of soil "nutrients" on plants
11. Determine components of soils
12. Classify soils

Satisfied with the list, he turned to available reference books, slides and films that he could use to supplement the learnings obtained from the firsthand learning situations. He also listed a number of activities that would help pupils summarize and organize their learnings.

Not until the last step in his planning did Mr. Barker list the learnings which he thought would result from the activities he had chosen. These became his specific subject matter objectives. They are listed below:

1. Soil drainage and capillarity vary in different types of soils.
2. Clay and humus help retain water in soil; sand and gravel increase drainage.
3. The structure of soil depends upon the relative amounts of sand, gravel, clay and humus.
4. Good garden soils are neutral or slightly alkaline; the pH can be changed by adding lime, peat moss, and chemical fertilizers.
5. Humus is the product of decomposition of organic matter.
6. Top soil differs in structure and components from subsoil.
7. Fertilizers add components needed for proper plant growth.
8. Soil is an important natural resource that must be carefully used to avoid damage.

The above technique for establishing objectives makes full use of local resources. The only learnings expected are those that can be attained satisfactorily by the means at hand. Emphasis is put upon "learning by doing." With care in the selection of activities the specific learnings lead towards an understanding of broad generalizations.

Pupils and subject matter objectives. Pupils must have objectives if they are to work purposefully. The ideal situation is reached when pupils adopt the teacher's objectives as their own and work toward them. This happens in those portions of the program that are built upon their immediate needs. Adolescents want information about sex.

Boys want to learn about automobiles and how to be physically outstanding. Girls want to learn about cosmetics and how to be attractive.

Outside these portions of the program, however, young people are less likely to accept the teacher's subject matter objectives. Few of them are imbued with a love of learning for its own sake. They rarely show interest in inclined planes and protoplasm as abstract ideas.

The teacher who looks beyond the immediate needs of adolescents towards some of their future needs and towards the needs of society may attain his subject matter goals by setting them up parallel to objectives which his pupils will accept readily. He may make use of adolescent urges to produce tangible things, to manipulate, or to work with close friends. As pupils work toward their own objectives, they develop the learnings and skills that the teacher believes they should have.

Below is a list of a few teacher objectives and some corresponding pupil objectives that would result in the same learnings.

Teacher objectives	*Anticipated pupil objectives*
To show how fuses protect homes	To overload a fuse and make it "blow"
To teach the principle of the photoelectric cell	To set up a system that will ring a bell when a person passes nearby
To determine the conditions needed for seed germination	To make seeds grow
To learn how to read a topographic map	To find home and other familiar places on a map
To learn the parts of a plant cell	To use a microscope
To understand the importance of good posture	To be more popular
To learn the names of common trees	To make a leaf collection
To study drainage in soils	To set up an experiment that shows difference in drainage.

These are illustrative only. Pupils react differently in different situations. Commonly several different pupil objectives must be set up for each teacher objective in order to provide for a wide range of pupil interests. The teacher must depend upon his knowledge of his own pupils in trying to set up pupil objectives.

Even as pupils work towards their own goals, the teacher should help them become conscious of their subject matter learnings. At the conclusion of an assembly program produced by a science class, a portion of a period could be spent profitably in summarizing the learnings that resulted; later these same learnings could be tested and grades given for achievement. Thus pupils find added satisfaction in the knowledge that they are working towards the broad goals of education.

When science content is properly chosen and utilized, two types of outcomes may be expected—increased knowledge and improved ways of thinking and behaving. What outcomes might be expected from this field study of woodland soil if the teacher exploits the situation to the utmost? By what means can the teacher do this?

INTERPRETING GENERAL EDUCATION GOALS FOR THE SCIENCE PROGRAM

In chapter one the function of the secondary school was described as a seven-fold task. These same responsibilities are now restated as objectives:

1. To help each pupil fit himself into his society
2. To improve his health and personal adjustment
3. To help him appraise himself realistically
4. To encourage his independence
5. To give him a broad range of exploratory experiences
6. To give him skills and understandings needed for meeting the problems of everyday living
7. To prepare him for the experiences of later adolescence and approaching maturity

These objectives are stated so broadly that their applications to science teaching are not immediately obvious. They need special interpretation before they can determine what is done with the content of the science program.

Professional literature contains the results of many different attempts to break down broad general objectives into more usable form.[2] (See page 308.) *Curriculum groups usually spend considerable time on this* phase of planning. However, the final statements, succinct as they must be, have deep significance only to those who make them or who have made their own. There are too many implications to be expressed adequately in a single sentence.

Each science teacher, early in his career, should take time to think through the purposes of his teaching. His thinking will run into paragraphs and chapters, but at the end he can sum up his thought in a few brief statements that will guide him in all his future planning and classroom teaching.

Helping young people fit themselves into their society. Young people need extensive practice in working together, both in large and in small groups. The science program abounds in opportunities for group work. A large share of the desirable activities are best carried out by groups of two or four pupils each. There are also many opportunities for pupils to participate actively in larger groups.

Group organization may be completely informal. Two or three pupils may undertake a special project even as the remainder of the class continues with its regular work. Such a group needs little supervision and may work in a corner of the laboratory, in the library, or in the science preparation room. Among the projects which one of these groups may assign to itself is the preparation of a demonstration to present to the class, the building of a model, or the writing of a report.

Formally organized group work may be employed. A class may be divided into groups of different interests, each group working on its own problem. Or the class may be divided into equivalent groups, each of which contains individuals of special abilities, one member being a good leader, another an artist, another a good writer, another with mechanical skills, and so on.

The science program can be used to encourage pupils to work in groups outside school hours. Pupils like to work on projects at each other's homes. They like arranging visits to see natural features of the region. They like to go in two's or three's to interview authorities for answers to special questions.

[2] For an excellent summary of some of these efforts see chapter two of Heiss, E. D., Obourn, E. S., and Hoffman, C. W., *Modern Science Teaching*, Macmillan, New York, 1950.

DESIRABLE OUTCOMES OF A SCIENCE PROGRAM *

Subject matter gains:

1. To acquire information useful in solving the problems of everyday living.
2. To acquire information essential for the proper care of our bodies.
3. To acquire information essential for the development of proper attitudes towards the conservation of our natural resources.
4. To acquire information helpful in the wise choice of vocations and avocations.
5. To acquire information assisting in the development of an appreciation of the environment and the processes that take place in it.
6. To acquire information that develops an understanding of the responsibilities of the individual and society.

Attitudes:

1. To develop a critical attitude towards any statement.
2. To develop an attitude of openmindedness.
3. To develop a wholesome attitude towards sex and sex relationships.
4. To develop a sympathetic attitude towards the problems of other living things.
5. To develop an attitude of respect for the achievement of scientific research.
6. To develop a sense of responsibility in the individual for his place in society.

Habits:

1. To develop the habit of looking for cause and effect relationships.
2. To develop the habit of delayed judgment.
3. To develop the habit of being critical of authority.
4. To develop the habit of looking to experiment for proof.
5. To develop the habit of being inquisitive.
6. To develop the habit of using all the senses.
7. To develop the habit of noting new achievements in science.
8. To develop desirable health habits.

Skills and Abilities:

1. To develop the ability to use the scientific method.
2. To develop skills in handling the common materials of the environment.
3. To develop creative abilities as applied to science fields.
4. To develop ability to read scientific material.
5. To develop the ability to write and speak about science.
6. To develop the ability to draw sound conclusions.

* Prepared by a summer workshop group of science teachers at the University of Omaha, 1947.

Special mention must be made of the opportunities for social participation provided by science clubs and science fairs. Once the pattern for conduct of these institutions has been established, pupils are able to conduct them with remarkably little supervision. They gain practice in conducting the affairs of organizations. They have increased contacts with adults as they invite speakers, judges and reporters to their functions.

Maintaining physical health and well-being. As boys and girls advance towards maturity, their need for information about themselves increases. They come less and less under the direct supervision of adults. In rebellion against the ways of childhood they are apt to refuse the counsel of parents. They need understandings that will help them make up their own rules for taking care of themselves.

The scientific approach to the care of the human body is more effective than indoctrination. Pupils who have made a survey of fire hazards in their homes understand better the need for precautions. Pupils who have made a study of pedestrian reactions at busy intersections are more likely to use caution themselves in similar situations. Pupils who have studied the dietary choices of their schoolmates are more conscious of the need for making wise decisions in selecting foods.

The scientific approach permits pupils to arrive at their own decisions. A boy or girl may refuse to accept an arbitrary statement by an adult, but if he understands the principles involved he is apt to accept the same conclusion for himself. And of great importance, he is able to substitute a new conclusion if he should be presented with new evidence.

The biological segments of the science program have long accepted responsibility for helping pupils maintain their physical health. Most of these courses include material on the study of the human body, on the nature of diseases, and on health practices advocated by health specialists.

The physical sciences can make equally important contributions, but full advantage of these opportunities is rarely taken. All adolescents are in great need of information about the behavior of objects in motion, including themselves, their bicycles, and automobiles. Older adolescents are in special need of understanding the behavior of automobiles at high speed. These understandings are best developed during the study of mechanics.

Mr. Neale organized a unit on automobile behavior for his ninth grade science classes. Pupils began with experiments in which toy trucks were rolled down inclined planes to compare the energies developed under dif-

ferent conditions. These learnings were applied to full scale automobiles traveling at various speeds.

On a field trip the pupils were taken to see an automobile that had been wrecked in a high-speed collision. On the way back to school the pupils stopped at a body shop to learn something of the magnitude of the forces needed to straighten even minor bends in frames and axles.

The unit continued with a study of reaction time and the distances cars might travel during the reaction-time interval. These distances were laid off on the street in front of the school. To these distances were added those needed to stop cars with good brakes. The unit culminated with a demonstration by the police safety bureau using a car equipped to show stopping distances at various speeds.

Understanding sex. It is but natural that pupils of high school age should be concerned with sex. The changes within their own bodies and the social pressures exerted from every side inevitably make them conscious of this facet of their existence. The effects of their interest can be either healthy or unhealthy depending upon the attitudes developed during this period.

Adolescents need help in adjusting to the experiences of sex that now face them. They need both knowledge and a frank attitude towards the topic. The purely physiological aspects of sex are easily handled in the science program. Basic understandings and a much needed vocabulary can be developed through a study of reproduction in plants and animals. Thereafter in a study of human reproduction young people find nothing unusual or mysterious.

Boys and girls need more than a knowledge of the biological aspects of sex to meet situations wisely. They need understandings about the social and moral aspects as well. This is a problem that requires the cooperation of many agencies. The science program must assume its share of the responsibility.

Helping pupils with personal adjustment. Adolescence is a difficult period for boys and girls. They are discarding the safe and tested relationships of childhood and starting out again to make completely new adjustments. Their values are changing rapidly; they want the status of adults and the approval of their fellows more than anything else. They tend to be abnormally conscious of their limitations and they often ignore their real strengths.

Probably the greatest help teachers can give adolescents is a sense of security. Teachers can help them recognize their strengths and compensate for their weaknesses. They can help them win the approval of their peers and find a place in the society of their fellows.

The diversified nature of the science program permits teachers to

observe pupils under various conditions and thus determine their special strengths. Once these abilities have been discovered, teachers can provide opportunities for pupils to develop their talents and build the self-confidence that comes with success.

Success may improve personal adjustment by drawing attention away from limitations. Commonly an adolescent's failure to fit into his world is due to internal doubts about his own worth, doubts that cause uncertain and awkward behavior. But if he finds success he may discover that his weaknesses are trivial or imagined, and he now approaches situations from which he might once have fled.

Billy was having trouble adjusting to the junior high school. He was pitifully self-conscious—blushing, stammering, shrinking, moving clumsily—whenever he found himself the center of attention. His classmates, with typical adolescent callousness, made him the butt of their jokes and called him "Pinky."

Billy's science teacher heard that Billy displayed real ability in mathematics classes and that he lost some of his self-consciousness while explaining the solutions of problems. It was easy for this teacher to provide problem situations involving mathematics in general science. Billy quickly outshone the others and participated more fully in class work. His classmates began to term him a "mathematical whiz." By the end of the year, Billy was an accepted member of the class and had lost much of his shyness.

The effort that Billy's science teacher needed to put forth to provide situations favorable for Billy's growth was trivial, but the results were tremendous. Science teachers can do so much to help their pupils in this way, not by neglecting the subject matter aspects of their program but by actually strengthening them.

Helping pupils appraise themselves realistically. The school population of today is a varied one. Represented among the student body are all manner of special talents and skills. Rarely is there a pupil who seems to possess no capacity whatever. However, our schools have long preoccupied themselves with academic skills alone. The unhappy result has been that large numbers of pupils lacking high ability in academic work have become convinced that they are complete failures —that they lack all capacity for success.

Our society has in it a place for each person, no matter what his type of ability. Indeed, our society must have individuals with different skills. For our schools to function properly, they should help each pupil appraise himself realistically, give him pride in his special talents, and guide him into the role most suited to him.

The science program presents many opportunities for pupils to

discover talents they did not suspect, and thus to emerge from a feeling of general inadequacy. The science program also helps young people find compensating satisfactions when they are disillusioned with the abilities they hoped to possess.

Godfrey was fully determined to become a veterinarian. His choice did not seem realistic because it was doubtful whether or not his family could afford the five years of training he would need, and because Godfrey did not seem to possess the academic ability that would win him scholarships. Nevertheless his general science teacher encouraged him to send for college catalogs and learn all he could about entrance requirements, the nature of the course work, and the opportunities for graduates. At the same time he invited Godfrey to join the science club and engage in its activities.

The suspicions about Godfrey's lack of academic abilities were confirmed as Godfrey progressed through high school; he was barely able to maintain passing grades in some of his courses. But even as he was being disillusioned about his academic ability he was finding deep satisfaction in his work with photomicrography, which had developed from his science club activities. His pictures were of near-professional quality and won him much commendation.

So instead of becoming depressed, Godfrey actually grew in poise and self-assurance as he went through high school. Seemingly without regrets he abandoned his plans for veterinary school and investigated careers in medical photography, finally deciding upon a school that provided work experiences during which he earned money that helped him with his expenses.

Encouraging independence. When boys and girls set up experiments they have planned themselves instead of blindly following directions, when they check books against reality, when they politely but firmly correct their teacher's mistakes, they are on their way to being independent.

The independent person comes to conclusions only after careful deliberation. He questions authority, not rebelliously, but in terms of the qualifications of that authority. He maintains reservations in accepting the conclusions of others until he has made his own investigations. His mind is always open and he is willing to change his opinions when confronted with new evidence. He is tolerant of the opinions of others and can prove them wrong without gloating. These characteristics are so typical of the true scientist that they are often referred to as the "scientific attitude" or the "scientific way of thinking." However, they are not confined to the scientists, nor is this way of thinking confined to science subjects. Independence of thinking is universal in application.

Science teachers are in an advantageous position to develop this type of thinking. Much of the material with which they deal is commonplace. Pupils can solve many problems by experiment and by direct observations in the field. They can check the statements of books, teachers, and other authorities against reality. They can resolve conflicting conclusions by checking and rechecking data. Little of the material they study is controversial. They are able to make decisions without the handicaps of prejudice and superstition. They do not become emotionally involved, as when they are considering problems of religion, race, politics and social relationships.

Independence of thinking is fostered in the science program by extensive use of problem solving situations. In this type of teaching pupils are challenged to discover their own facts and draw their own conclusions instead of being forced to depend upon others for their thoughts.

Independence of thinking is a product of increased pupil participation in the planning process. Pupils have opportunities to define their own problems, suggest methods of attack, delegate responsibilities, and accept their own results with no more than minimum guidance from the teacher. Independence of thinking is stifled in the teacher-dominated classroom.

Giving pupils exploratory experiences. Every young person needs opportunities to explore his own strengths and weaknesses, his likes and his dislikes. He needs opportunities to study the world about him and the things in it. One requirement for exploration is freedom. No one can be forced to explore; he must follow his own interests. Another requirement is a broad range of situations in which to work. Pupils will not explore areas in which they feel certain of failure. They will not explore situations that seem to present no challenge.

Occasionally pupils express a wish to explore areas in which the teacher feels there is small likelihood for success. They should have freedom to do so. It is far better for a person to discover his own limitations than to be told about them. Equally important, pupils often have unsuspected abilities that are revealed only when the pupils put themselves to the test. Pupils need opportunities to fail as well as to succeed. Only by failure can they discover their limitations. But they should be able to balance failures with successes, and failures should not result in condemnation and ridicule.

Project work in science permits individual exploration of interests and abilities. Through the use of projects for individuals and for small groups almost every type of need can be met. Within one unit, for instance, projects may be as simple as the preparation of a chart based

how to lubricate a bicycle or clean dirt from under their finger nails, or use a fire extinguisher, or care for a pet, or store athletic equipment. It is better to help them practice problem solving on these situations than on hypothetical situations that may never develop. They benefit more from studying the principles of buoyancy as applied to themselves in a swimming pool than by a study of submarines. They are benefited more by learning how to apply the laws of stability to themselves while dancing than by a study of gravitational forces on the moon.

The science program can be built up almost completely on a problem solving basis. *To be most useful to the pupils, the situations should* be as realistic as possible. Many problems can be taken from real life. Other problems can be so similar to real life problems that transfer is easy.

Helping pupils with personal grooming. Many pupils need help with personal grooming, particularly when the home fails to emphasize this aspect of social living. Most pupils need information about soaps and deodorants, about shampoos and hair dressings. They need understandings about procedures for cleaning their clothing. They need information about diet and its effect on appearance. They need help with posture and choice of dress. The science program, though not the only agency with obligations in this area, can provide a good part of the needed information and specific help.

Chuck had ended his preadolescent rebellion against the forced washings of childhood and was giving more attention to personal grooming. He completely neglected his fingernails, however, and they were most unattractive.

Had the science teacher directed attention openly to Chuck's begrimed nails, Chuck would have resented being treated like a child. So, during a unit on personal health, the teacher appointed three attractive girls to list the characteristics they liked to see in boys. Clean fingernails were among the items listed. Chuck rarely failed to clean his fingernails after that.

Within the science program there are many other opportunities to make pupils conscious of the need for good grooming. Any discussion of good practices is certain to call the attention of individual pupils to their own carelessness even though the discussion is kept impersonal. Personal inventories that list hair, eye, and skin color help pupils recognize the need for color harmonies in their dress. Analysis of individual posture, especially with the aid of a three-leaved mirror, helps a pupil recognize his need for corrective measures and properly styled clothing.

Preparation for later experiences of life. Adolescents have so many immediately pressing problems that they are little apt to be concerned

with the remote future. True, they think in a vague way about their activities as adults but they are usually more certain about what they do not want to do than about what they want to do. Even when a young person has decided upon a career, it is rare that he will work towards ends that can be realized only a decade or so later; he will usually work towards more immediate ends.

Science programs have long been organized on the preparatory basis alone and have been universally condemned by educators who look at schooling broadly. Science programs can be effective only if they recognize the immediate needs of pupils. However, the preparatory function need not be neglected. It is usually possible to work towards several objectives at the same time. A boy learning about an automobile he wants to drive now can be gaining understandings of mechanics he can put to good use later in life.

Consumer information. When boys and girls leave school and take full responsibility for their money, they are in need of information that is sometimes taught as "consumer science." This information helps them buy wisely and take care of what they have. The study involves economics, science, and conservation. It includes a study of advertising claims, manufacturer's recommendations, testing procedures and relative values.

Boys and girls will also need information someday about family life and care of the home. They should be able to take care of electrical equipment, heating plants, and automobiles. They should know how to plan diets, maintain sanitation, and take care of pets. They should be able to plan and take care of lawns and gardens.

Younger pupils feel little pressing need for such information; whatever is taught must be included in activities that have more direct appeal. As pupils near graduation, however, many of them become more aware of the future. Senior high school courses can afford to give substantial blocks of time to the study of consumer science.

Vocational exploration. Among the incidental outcomes of exploratory work in the science program is an expanded acquaintance with the nature of scientific occupations. Vocational opportunities in the science field range from laboratory technicians who need little academic ability or training to research scientists who need almost a decade of rigorous training. Ever since World War II the demand for all types of scientific workers has far exceeded the supply.

It would not be wise to set up a science program as a vocational guidance program. To do so would limit its usefulness. But teachers can provide many opportunities for pupils to consider the types of work being done in different scientific occupations. They can allow

pupils having special interests to investigate further the nature of these jobs and the training required.

Pupils may discover from their experiences with science materials whether or not they would like the type of work required in certain occupations. They may someday be able to use this experience in choosing a field in which to work. It may also prevent them from choosing an occupation for which they are temperamentally unfitted.

Avocational exploration. One lasting contribution of the science program is the development of healthy interests. Many of the activities—model making, bird study, collecting, gardening—lead directly into healthy, satisfying, leisure-time pursuits.

Perhaps it is to this aspect of science education that so many authorities refer when they speak of developing an appreciation of the environment. Certainly as adults move past their first troublesome years and have time to look about them, they can find deep satisfaction in the things in their environment. It is during these later years that gardening, mineral collecting, bird study and photography have such great value in maintaining emotional and physical health.

Conservation education. Conservation practices become increasingly needed as the population of this nation grows and as serious inroads are made on the natural resources. In many instances in the past waste accounted for as much of the depletion as did use. The picture is but little better today. Most people now recognize in a general way the need for more careful use of their natural heritage, but few see where specific applications can be made and how the problem relates directly to themselves. Non-renewable resources dwindle at an appalling rate. Soils continue to wash downstream. Use of timber still exceeds yearly growth. And the nation's beauty spots, so needed for an expanding population, are gradually transformed into junk piles, slums, and cheap amusement arcades.

The science program is obviously in a position to make some of the most important contributions to conservation education. Science deals, among other things, with animals, rocks, soil and water, and with the scientific principles that control these natural features. The science program is well adapted to help meet the three general objectives of conservation education: (1) to give information about natural resources, (2) to develop desirable attitudes towards the use of these natural resources, and (3) to give experiences with conservation practices.

The secondary school science program should give attention both to the broad aspects of conservation and to the more limited aspects that affect pupils directly. An understanding of the problems in con-

serving the nation's forests, its soil, its water supply, and its minerals will be of importance within a few years when boys and girls become voting citizens and must decide upon matters of public policy. But more real to them are the understandings that help them make immediate decisions—the care of tools and machines to conserve minerals, the reduction of food spoilage to reduce soil depletion, fire prevention to conserve lumber, and the reduction of heat losses from homes to help save fuel.

Attitude development is a natural outcome of building a background of understandings. Having seen a badly eroded pasture and having learned the value of topsoil and the difficulty of replacing it, pupils see immediately the waste and the need for conservation practice. They need no indoctrination; they draw their conclusions from the facts.

Helping with academic skills. Success in the adult world is likely to depend in large part upon such academic skills as reading, speaking, writing and computation. These skills are essential for many of the activities of daily living and almost all vocations utilize some of them.

Pupils entering the secondary school have been given practice with certain elementary phases of these skills but they have been no more than introduced to the more advanced phases. No pupils have mastered the skills; some, for one reason or another, are seriously deficient. The function of the secondary school is to take up where the elementary school left off, remedying weaknesses and providing practice needed to bring about general improvement of these skills.

Subject matter specialists do not always recognize their obligations to help develop academic skills. A survey of 2,275 schools showed that guidance in reading was provided by:

1,602	English departments
871	Social studies departments
341	Natural science departments
265	Foreign language departments
228	Mathematics departments
167	Commercial departments
48	Practical arts departments
23	Fine arts departments [3]

Such data indicate that most secondary school teachers assume either that pupils should have mastered reading by the end of the sixth grade—a ridiculous assumption—or that the responsibility for further development belongs to someone else—a shocking assumption

[3] "Reading Instruction in Secondary Schools," Research Bulletin of the National Education Association, Vol. 20, No. 1, Washington, 1942.

in the light of the importance of this skill to the young people who must depend upon it for success in later life. Could similar surveys be made for the other skills it is likely that similar negligence would be revealed.

None of the objectives of the secondary school is more important than the development of academic skills. Science teachers can meet their obligations by taking advantage of the strong interests developed in science to encourage reading for information, mathematics for helping obtain information directly and for making information more meaningful, and writing and speaking so that information can be shared with others. Later chapters will give specific helps for attaining this objective through the science program.

Suggested activities

1. Write up a list of specific subject matter objectives for a unit entitled "The Human Body."
2. List the long range subject matter objectives for an integrated course in physical science for the twelfth grade.
3. According to the broad concept of the educational program, our schools should help an individual (1) to understand himself better, (2) to solve the problems of everyday living, (3) to adjust himself to his society. Obtain syllabuses in chemistry, physics, biology and general science as developed for a single state or local school system. Set up four committees to investigate how each of these syllabuses respectively contributes to these general goals.
4. Begin making a list of the general objectives which you believe should govern your teaching. Discuss your list with others and modify the list as your ideas change. Keep the list to guide you during your cadet teaching experience.

Suggested readings

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Heiss, E. D., Obourn, E. S., and Hoffman, E. W., *Modern Science Teaching,* Macmillan, New York. 1950, Chapter II.

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A Program for Teaching Science, Thirty-first Yearbook of the National Society for the Study of Education, Part I, Public School Publishing Company, Bloomington, Ill., 1932.

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"Science in General Education," Report of the Science Committee of the Commission on Secondary School Curriculum, Appleton-Century Company, New York, 1938.

chapter 13

PLANNING SCIENCE LESSONS

Monday morning Miss Johnson met her general science classes with only the vaguest of plans in mind. Things went badly from the start. The pupils were restless and little interested in the material she was trying to present. The dismissal bell had a welcome sound.

"My!" sighed an exhausted Miss Johnson as she walked from the building with another teacher, "Pupils just can't settle down on Monday, can they?"

Miss Johnson spent half an hour or so Monday evening writing plans for the next day's lessons. Tuesday morning she went to school a little earlier than usual to prepare materials called for by her plans. As she gathered equipment for experiments and as she set up demonstrations, she found herself beginning to look forward to her classes.

Teaching was much more enjoyable all day Tuesday. The atmosphere was relaxed and everyone seemed to be having fun. Goals were attained smoothly. Time passed swiftly. Miss Johnson ended the day tired but with the contentment that comes with a job well done.

Careful daily lesson planning is the key to successful teaching. Regularly looking ahead permits a teacher to anticipate pupil reactions, to prepare adequately to utilize these reactions, and to avoid foreseeable difficulties. Lack of planning encourages fumbling and indecision, with accompanying disciplinary problems.

A teacher without plans ends his day tired from his efforts to keep classes running smoothly and discouraged with his lack of success. A teacher with good plans is also tired, but his tiredness is tempered

with satisfaction and with anticipation for the next day's work. There is all the difference in the world between the two.

THE INFLUENCE OF PLANS ON PUPIL BEHAVIOR

Attention is a form of pupil behavior that can be observed readily. Since attention is essential for learning, even though it may not insure learning, and since it can be measured more conveniently than interest and achievement, it makes a good criterion for judging the effectiveness of lesson plans. Other criteria must be applied as well but none show up the strengths and weaknesses of teaching procedures so effectively as observation of pupil reactions to material presented.

Analyzing the performance of lesson plans. On the following pages four science lessons are analyzed in terms of pupil attention. The data were collected by a single observer sitting at the rear of the classrooms. At one-minute intervals he recorded the number of pupils who seemed to be concentrating upon the lesson. He also made note of the type of classroom activities being carried out during the lesson.

Later, the percentage of pupils showing attention was calculated for each interval, using the total enrollment of the class as a base. These percentages were plotted against time as shown in figure 12.

The resulting curve in each case indicates general shifts of class attention but tells nothing of individual pupil behavior. Should two points on the curve show ninety percent attention there is nothing to tell whether the same or a different group of pupils were giving attention at each time.

The areas above and below the curve have interesting significance. The area under the curve represents in pupil-minutes the portion of the period during which desired learnings may take place. The area above the curve represents in pupil-minutes the portion of the period during which desired learnings undoubtedly do not take place.

Analysis of a tightly planned lesson. The lesson analyzed in figure 12 was taught by a cadet teacher who won high praise from his sponser teacher for his excellent class control. Analysis of this lesson, typical of others he taught, gives the reasons for his success.

The subject of the lesson was boiling water. During preceding lessons the pupils had studied other properties of water. At point A on figure 12 the teacher announced that two pupils would perform a demonstration they had prepared beforehand. The pupils heated a stoppered flask containing a little water and made the cork pop out. On request they repeated the demonstration. Then they explained the cause.

At B the teacher resumed charge of the class and reviewed the steps and outcome of the demonstration. During his review he asked what steam looks like. Several arguments started at C and continued to D. To settle the dispute the teacher placed a flask of hot water over a gas flame at D. While the pupils were waiting for the water to boil and produce steam he directed them to make diagrams of the apparatus

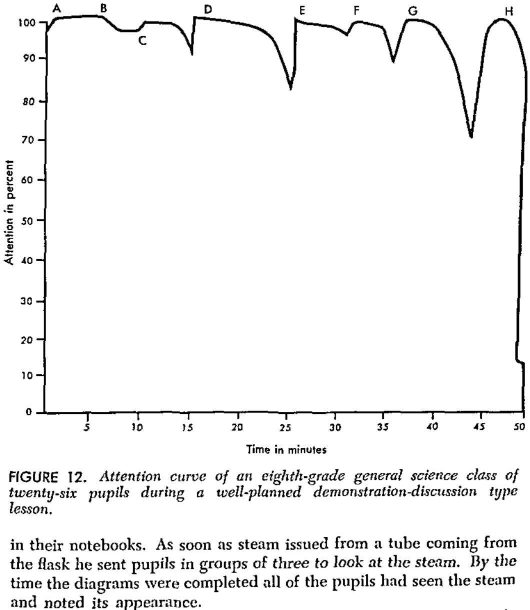

FIGURE 12. *Attention curve of an eighth-grade general science class of twenty-six pupils during a well-planned demonstration-discussion type lesson.*

in their notebooks. As soon as steam issued from a tube coming from the flask he sent pupils in groups of three to look at the steam. By the time the diagrams were completed all of the pupils had seen the steam and noted its appearance.

At E the teacher interrupted work long enough to help the pupils summarize their observations and label their diagram correctly. He allowed a few more minutes for completing the diagram at F.

At G he asked if any pupils knew the temperature of boiling water. Several pupils suggested 212° and two suggested 100°. To obtain an

authoritative answer the teacher directed two pupils to put a thermometer in the flask of hot water and heat it again.

Attention wandered a little while the pupils were waiting for the water to boil but returned again at H as soon as the boys began to read the thermometer. During the last five minutes the teacher asked the pupils to summarize their learnings in their notebooks. Most pupils completed the assignment quickly and sat waiting for the end of the period.

This was a tightly planned lesson and was admirably taught. There was no confusion and little noise. Rarely was the attention of more than two or three pupils diverted from the subject at one time. The weakest point in terms of attention was the interval during which pupils waited for the water to boil the second time.

The lesson was rather formal and did not provide many opportunities for individual initiative or for independence of thinking. However it was well suited for a beginning teacher who did not feel in complete control of the classroom situation.

Analysis of a lesson based on project work. The lesson in figure 13 was taught by a master teacher of several years' experience. His pupils were making dioramas representing various types of environments, working in groups of two or three. Planning and preparatory work had been done in previous periods.

The pupils came to order quickly at A but the teacher was interrupted by a messenger from the school principal. At B the teacher announced that the class would resume work on the dioramas. For the next several minutes all pupils were busy getting out their materials and beginning work. The teacher moved from group to group answering questions, finding needed materials and helping with techniques. For several minutes at a time he gave full attention to one or another of the groups.

At C there were definite signs of slackening interest. Increasingly the pupils began to move about the room and talk with each other. It was difficult to determine how much of this talk concerned the projects. Nonetheless, work on the projects continued satisfactorily.

At D there was a rapid decline in attention. Two pupils left the room for drinks. Three boys left their own groups and distracted other pupils. Two of the boys scuffled with each other but stopped when the teacher looked their way. About fifteen minutes before the end of the period, at E, one group of pupils began to put away its materials. Other groups followed suit and within seven or eight minutes almost half the class had nothing to do.

The teacher who was busy with one group had failed to notice what was happening. When he did at F, he announced loudly that the

period was far from over and that the pupils should keep on working. Most of the pupils resumed work but five minutes before the bell rang interest began dropping rapidly again. By the end of the period all but one group had put away its materials and sat waiting for the dismissal bell.

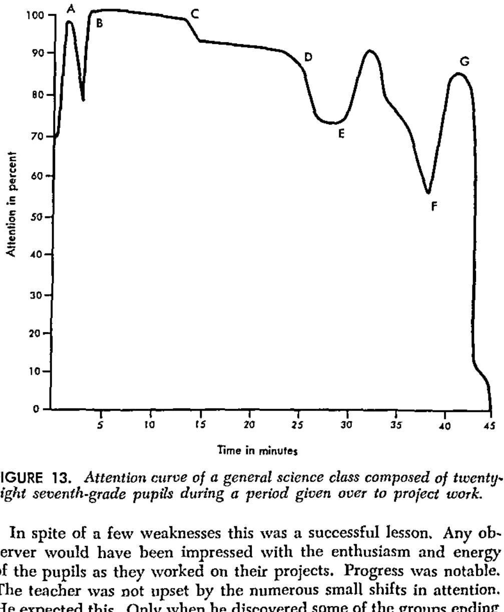

FIGURE 13. *Attention curve of a general science class composed of twenty-eight seventh-grade pupils during a period given over to project work.*

In spite of a few weaknesses this was a successful lesson. Any observer would have been impressed with the enthusiasm and energy of the pupils as they worked on their projects. Progress was notable. The teacher was not upset by the numerous small shifts in attention. He expected this. Only when he discovered some of the groups ending work *prematurely did he exert his authority.*

In criticism one might say that the one type of activity was extended for too long a time for some of the pupils, *although about half the* class maintained high interest almost to the end. There should have been some provision for those pupils whose interest waned *the most* rapidly.

Analysis of an improperly planned lesson. The lesson analyzed in figure 14 was taught by a cadet teacher who had little control of his pupils and who did not recognize that his difficulties stemmed from careless planning. The lesson dealt with uses of compressed air. In previous lessons the pupils had studied the common properties of air, including its elasticity.

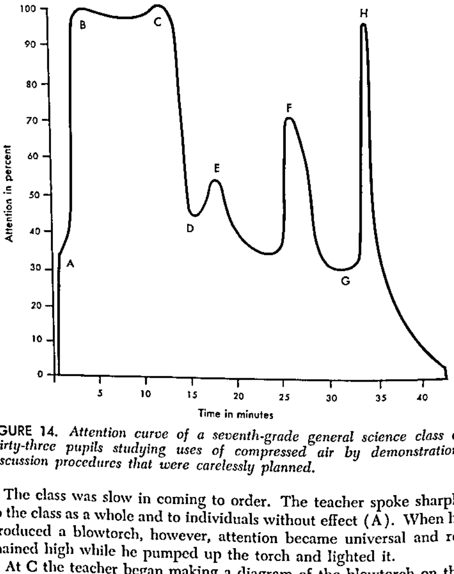

FIGURE 14. *Attention curve of a seventh-grade general science class of thirty-three pupils studying uses of compressed air by demonstration-discussion procedures that were carelessly planned.*

The class was slow in coming to order. The teacher spoke sharply to the class as a whole and to individuals without effect (A). When he produced a blowtorch, however, attention became universal and remained high while he pumped up the torch and lighted it.

At C the teacher began making a diagram of the blowtorch on the blackboard, turning his back on the pupils without giving them directions for anything to do. A few pupils copied the diagram in their notebooks but the majority did not feel obligated to do so. The teacher ignored the increasing disturbance during the three minutes he took to make the diagram.

At B the teacher picked up a convection box and explained its use. Interest was high while she set up the demonstration but dropped quickly because only the pupils in the front rows could see the smoke in the box. The teacher asked two pupils to describe what they saw.

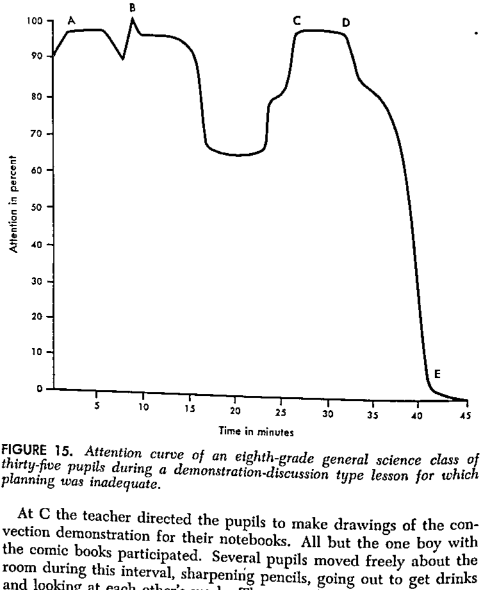

FIGURE 15. *Attention curve of an eighth-grade general science class of thirty-five pupils during a demonstration-discussion type lesson for which planning was inadequate.*

At C the teacher directed the pupils to make drawings of the convection demonstration for their notebooks. All but the one boy with the comic books participated. Several pupils moved freely about the room during this interval, sharpening pencils, going out to get drinks and looking at each other's work. There was little noise and no confusion. At D pupils began finishing the assignment. The teacher had nothing planned for the remainder of the period. Five minutes before the end of the period all had finished and sat patiently watching the clock.

The faults of this lesson could have been corrected easily. Her plans were inadequate. She did not have enough material to fill the period.

She thought not in terms of pupil growth but only in terms of subject matter. She had given no attention to the visibility of her demonstration. A few more minutes spent in planning and a little more in preparing materials and her lesson would have been completely successful.

Anticipating pupil behavior. Lesson planning is made much more effective by looking ahead to the possible reactions of pupils in each new situation. Analysis of a large number of lessons has produced several generalizations that can be used as guides in anticipating pupil behavior. These generalizations are listed below:

1. Class attention is gained quickly by introducing a new activity.
2. The longer an activity is continued the more rapidly the attention level declines.
3. Activities vary in their ability to hold attention.
4. A change to an activity distinctly different from its predecessor raises the level of attention.
5. It is impossible to predict accurately how long class attention can be maintained by any one activity.
6. The attention level drops quickly when pupils have nothing specific to do.

Through the proper application of these generalizations it is possible to plan a lesson that maintains a high level of attention throughout a period. Such a plan reduces and may eliminate many of the problems of classroom control. It must be remembered, however, that control is not the only objective and that consideration must be given to other factors as well as to attention.

THE ACTIVITY APPROACH TO LESSON PLANNING

Could a lesson plan be no more than a list of topics to be covered, planning would be simple indeed. But boys and girls are not passive receptacles into which information can be poured as cream is poured into bottles. They are active human beings and their learning processes are active ones. Lesson plans must include the things pupils are going to do in order to learn, as well as the things they are expected to learn.

The importance of activities in learning. Learning requires action on the part of the learner. Even when a pupil is listening to a lecture, reading a book, or viewing a film his mind must be accepting new impressions and relating these to other experiences if he is to learn. Most science learnings require physical participation as well. First-hand experiences depend upon the use of all the senses; many important learnings depend upon manipulation in order that touch and the muscular senses be brought into action.

Activities have another role that is not fully appreciated. Associations do not occur spontaneously; incentives are needed. Occasionally pupils make associations with the deliberate intent of learning—perhaps they wish high grades or perhaps they wish to escape punishment—but usually they prefer to spend their energies in ways that promise more profit in terms of their immediate needs.

Properly selected activities provide the incentive that adolescents need to learn the things teachers consider important. The pupils make the associations, not for the sake of learning, but because they need the associations to carry out the activities which seem important to them.

If a class cannot be taken to a blast furnace, the demonstration of a working model may be substituted. The concepts gained will not be complete, and the demonstration will need supplementation by pictures, films, and readings, if the pupils are to gain adequate understandings.

Types and functions of learning activities. Many classroom activities—reading, viewing films, writing reports, taking tests—are primarily intellectual. Field work, laboratory work, and many projects require a large amount of physical participation as well. The former type, which some teachers label "passive learning activities," are satisfactory for presenting vicarious experiences and may be used in summarization, organization, and review exercises. The latter type are essential for

firsthand experiences and may also be used for some types of summaries, organization activities, and review exercises.

Some classroom activities are solitary in nature; these permit pupils to learn at their respective rates and in their respective ways. Other activities are social in nature; these take advantage of the gregarious instincts of adolescents and at the same time help prepare pupils for working together in adult life.

Some activities hold pupils to closely supervised patterns of action. When employing such activities the teacher has opportunities to direct learning along desirable channels. Other activities give the pupils more or less responsibility for their own actions. These last activities give practice in planning, in setting and working towards objectives, and in self-control.

Activities differ greatly in their ability to capture and hold attention. Spectacular demonstrations gain every eye immediately. Good films enthrall pupils for half an hour at a time. On the other extreme, there are reading exercises that interest pupils for a few minutes only and writing assignments that appeal to none.

Activities vary in the amount of initiative and independence of thinking they encourage. A dictated notebook exercise requires little mental activity but sometimes has value in providing each pupil with presumably essential information. Completely different are true experiments which may involve high level thinking.

Activities and the selection of subject matter. Many science topics are a pleasure to teach because so many appropriate activities may be utilized. Static electricity, for instance, provides many excellent lessons for general science because there are dozens of simple experiments, demonstrations without end, projects of all degrees of complexity, good films, and a great range of related readings.

On the other hand, certain science topics may be ill-suited for specific teaching situations because so few appropriate activities may be employed. The study of genetics, as one example, does not fit well into most general science programs. Genuine experimentation is rarely possible. Illustrative materials are lacking or few in number. Emphasis must be placed upon lectures, readings, charts and pictures —sources of information which few youngsters are prepared to interpret adequately.

Lesson planning includes a consideration of the teachability of the topics proposed for treatment. Certain topics for which few useful activities are available are judged unsuitable at the very beginning and are replaced by others which can be taught more satisfactorily.

The need for balance in utilizing activities. Every activity is apt to have a different impact on pupils. Some pupils may benefit greatly from a specific activity; other pupils may find the same activity meaningless. When several types of activities are used chances that each pupil will find something of value are increased. Learnings are usually increased through the use of several types of activities applied to one topic. Several experiences tend to reinforce a specific learning. In addition, the strengths of one activity help to compensate for the weaknesses of another.

Overemphasis on one type of activity may deny pupils important benefits. Too much socialized work is apt to discourage independent work. Too much individualized instruction and solitary activity keeps pupils from gaining practice in working together. An excessive quantity of reading takes the emphasis from first hand experiences, while too much manipulative work minimizes the value of books.

Classroom activities and classroom control. Activities planned for a lesson may have several functions. Each is chosen in terms of some limited subject matter objective. Each usually is directed towards some broad, general education goal. Each may also, by its interaction with other activities, play a part in classroom control.

Below is a brief lesson plan that was developed with the problem of control in mind. It provides a variety of activities and occasional opportunities to use the larger muscles:

Topic—Electromagnets

10:00-10:10: Ten question written quiz on properties of permanent magnets.
10:10-10:15: Pupils exchange papers and correct answers.
10:15-10:25: John and Herbert demonstrate the electromagnet they have built.
10:25-10:40: Pupils work in pairs making and testing an electromagnet. John and Herbert assist where needed.
10:40-10:50: Class discussion of results. Begin plans for discovering uses of electromagnets and making an exhibit of ways they are used.

The introductory activity puts an abrupt end to the freedom enjoyed during the changes of classes. During this solitary activity the pupils are held by the challenge of the test questions. Following this short period of intense concentration pupils are given an opportunity to relax and move about a bit as they check their test papers. The next activity, which has high interest through the use of student demon-

strators, welds the pupils into a single group. A comparatively long interval follows during which the pupils, acting in small groups, have opportunities to manipulate, to move about, and to let their interests diverge into different channels. The last activity brings the pupils back to act as a single group, restricting movement but encouraging controlled talking and free range of imagination.

Consideration for the specific qualities of science activities in the fashion described does much to eliminate discipline problems. Three or four completely different activities in one lesson provide welcome variety. Proper alternation of the several types ends rigidly controlled situations before pupils rebel, and puts an end to periods of freedom before they develop into license and anarchy. Classroom control problems almost always can be traced to over-long use of one activity, or to an uninterrupted sequence of activities that hold pupils under tight control for long periods.

Choice of activities for the insecure teacher. A beginning teacher or a teacher faced with a new group of pupils finds it wise to employ only activities that present few control problems. He may prefer to choose for his first few lessons only activities that require little special motivation such as those listed in the left hand column of table 10. Even the experienced teacher finds these activities useful on those difficult days that precede vacations or athletic events:

Activities that need little motivation	*Activities that need strong motivation*
Watching films and filmstrips	Preparing written reports
Watching demonstrations	Constructing elaborate models
Taking short field trips	Doing extended field work
Taking short tests	Taking long tests
Doing simple experiments	Doing mathematical exercises
Preparing simple demonstrations	Looking up answers to questions in textbooks and workbooks
Constructing charts and models within abilities of pupils	Doing extensive library research

TABLE 10. *Some common activities classified according to the amount of motivation pupils need in order to engage in them freely.*

Gradually, the teacher may work towards inclusion of activities listed in the right hand column. The first written reports may be short—a few sentences in length—and supplemented by diagrams and clippings. The first field problems may be limited in scope until pupils discover the challenge of these problems. Library research problems may be permissive in nature so as to appeal to pupils with adequate reading ability. As a teacher becomes better acquainted with his pupils

and knows their special interests and abilities, he may broaden the scope of these activities, sometimes requiring all pupils to engage in them, at other times making them permissive only.

The insecure teacher may also find it wise to alternate with intervals of tight control only such activities as are listed in the center column of table 11. The activities listed in the right hand column require considerable skill to handle properly. They also require pupils who are accustomed to taking responsibilities for their own actions. Both teachers and pupils need to work gradually towards full utilization of these valuable activities.

Activities that hold pupils to the same task with little freedom	*Activities that hold pupils to the same task but permit some freedom*	*Activities that permit pupils to work on different tasks with considerable freedom*
Taking tests	Watching demonstrations	Preparing demonstrations
Filling in blanks on worksheets	Doing laboratory exercises from direction sheets	Preparing charts
Reading in textbooks	Taking short field trips	Constructing original models
Writing up reports of demonstrations	Constructing models from kits	Doing library research
Making diagrams of apparatus	Examining specimens	Solving problems by experiment
Solving mathematical exercises	Studying prepared slides with a microscope	Doing field work
Looking up answers to sets of questions	Checking test papers and home work	Preparing reports of independent research
Watching films and slides		Setting up exhibits
		Producing plays and assembly programs

TABLE 11. *Some common science activities classified by the amount of freedom they permit pupils.*

MAKING A LESSON PLAN

It is important that daily lesson planning be reduced to the utmost simplicity. Science teachers are busy people. They usually have full schedules and additional responsibilities as well. They need all the time they can find for the preparation of materials, for working with especially interested pupils, and for keeping abreast of new ideas in science teaching. The time spent in actually writing plans should be kept as short as possible.

When to write a plan. The most advantageous time to plan a lesson is immediately after the preceding lesson. The extent and direction of

the material covered is fresh in mind. The interests of the pupils have been revealed. Past mistakes are still vivid.

Good lesson plans can rarely be made several days in advance. No one knows how far a class may go in a single lesson or in what directions their interests will lead the work. To try to hold a class to a precise amount of material each day stifles enthusiasm and initiative.

For the same reason a teacher should not try to make a single plan serve for several different sections, except perhaps on the first day of work. The nature of each section is different, not only because there are different pupils but because the pupils have different effects upon each other. But even though different sections need different plans these plans are only adaptations of a basic plan and materials prepared for one class can be used sooner or later for other classes.

The value of a schedule. The several activities used during the progress of a science lesson interact with each other, one activity being affected by those that have gone before and in its turn affecting those that come afterwards. Thus the order in which activities are introduced becomes important and the time allotted to each needs serious consideration.

A schedule for the activities enables the teacher to see at a glance how the final balance is working out. It shows whether one activity is being planned for too long a time to hold the attention of pupils. It shows whether there is adequate provision for the various talents and interests within a group. It shows whether the various types of activities are being alternated in the most advantageous fashion.

A schedule once prepared need not be considered as inflexible. Commonly an activity awakens more interest than was anticipated; the time allotted for it may well be extended. Sometimes an activity has little appeal; it is usually better to pass to another activity than to hold the pupils to something for which they see no purpose. Sometimes pupils themselves propose an activity that promises to be more profitable than those scheduled; plans may then be abandoned or modified as needed.

A form for lesson plans. A good lesson plan form is a real time saver. It reduces the amount of writing needed. It establishes patterns for procedures. It is a reminder of items that might be forgotten otherwise. The lesson plan form shown on page 336 is adapted from a form used by Dr. Philip G. Johnson of Cornell University. It is remarkably simple and very easy to fill in. Yet it provides for all the major features essential in a good plan.

The heading serves to identify the plan. It stipulates the topic to be dealt with and it provides for a listing of goals. The main body of the

DAILY LESSON PLAN

Class Chemistry, Section 3 — Date 11/6

Unit Acids and Bases — Topic Acids in Foods

Specific Objectives
- to review tests for acids
- to test common foods for acidity
- to discover importance of acids in foods

Time	Activity
10:05-10:10	Return quiz papers
10:10-10:20	Review tests for acidity with demonstrations
10:20-10:40	In teams of two, pupils test foods given them
10:40-10:45	Summary of results
10:45-10:55	Assignment—optional reports

1) Production of vinegar
2) Pickle making
3) Vinegar and taste
4) Kinds of vinegar
5) Vinegar as a preservative
6) Chemical reactions during making of vinegar
7) Test for citric acid
8) The citrus fruits
9) Uses of citrus fruits
10) Vitamin C and citrus fruits
11) Nature of vitamin C
12) pH of various citrus fruits
13) Variation in pH of oranges
14) Cause of sour milk
15) pH of buttermilk
16) Production of cheese
17) Production of butter
18) Sour cream cake
19) Making cream of tomato soup
20) pH of tomatoes
21) Making of sauerkraut

Assignment

Materials			References
Litmus paper	Tomato	Apple	
Phenolphthalein	Sweet milk	Pear	
Methyl orange	Sour milk	Pineapple	
Vinegar	Buttermilk	Grapes	
Orange	Tea	Cereal	
Lemon	Coffee	Cabbage	
Grapefruit	Cocoa	Sauerkraut	
	Peas		

plan is a schedule of the activities to be employed; both the order of the activities and the time considered appropriate for each are given. Space is left at the end of the schedule for the assignment. This does not imply that the assignment is to be given last. It is a device for directing attention to this important item.

Two boxes at the bottom of the sheet complete the form. One box is provided for a list of references—books, films, pictures—called for by the plans. The other box is provided for a list of materials required by the demonstrations and experiments planned. These lists are highly useful when the teacher is assembling his teaching aids in advance of the lesson.

This lesson plan form is duplicated on notebook paper punched to fit a standard looseleaf notebook. The reverse side of the sheets is large enough for the listing of questions that may be asked orally or written on the blackboard.

Establishing objectives for a science lesson. Only specific subject matter goals need be listed in a lesson plan. Major subject matter goals are listed in the unit plan and influence both the composition of the lesson and the direction it takes. General education goals are kept in mind at all times.

Subject matter goals suitable for a single lesson are necessarily limited, otherwise they cannot be attained within the allotted time. Providing major objectives are not forgotten, limited goals are desirable; they center attention upon a narrow area, make possible several different approaches, and encourage thorough treatment.

Subject matter goals for a lesson may be written as learnings. These are specific enough to be attainable within a period. Principles may be listed instead but these tend to be broad in scope and may lead to superficiality.

Organizing a lesson. Each lesson is constructed to fit a particular situation; there is no pattern that should be followed. True, within a series of lessons there must be provision for the introduction of new material, for summaries, for the organization of learnings, and for any needed review and drill. But no single lesson need contain each of these teaching elements; in general it will contain only two or three of them.

It is good practice to open many lessons with some activity that reviews work of preceding days. One may use for this purpose a short written test, a brief period of oral questioning, slides, or a film that fits the need. One may also repeat a demonstration or ask pupils to repeat some presentation. A daily review is not necessary. Commonly project work provides its own review.

Even the most experienced teacher cannot estimate accurately the length of time pupils will spend on an activity. They may want more than the estimated time, especially if the work is interesting. But if they have had identical work in previous grades, or if they are completely uninterested in the topic, they cannot be held to an activity as long as was estimated.

It is not uncommon to find that a lesson has moved more quickly than anticipated and that all the suggestions in the plan have been exhausted several minutes before the end of the period. There then comes an interval that is demoralizing to the pupils and discouraging to the teacher.

Though it is possible for a teacher to extemporize in such a predicament, it is far better to anticipate the possibility and over-plan each lesson, adding to the original schedule one or two additional activities. The time spent in planning the activities and preparing any needed materials is not wasted because if unused one day they may be included in the following day's plans.

Importance of the transition intervals. During a well-organized lesson the progression from one activity to the next is made so smoothly a casual observer may notice nothing remarkable. The pupils end one activity and begin a new one with little hesitation and confusion. However, such smooth transitions are the result of careful planning, they rarely happen by chance.

The importance of transitions is more readily understood by analyzing difficulties that arise because this aspect of planning was neglected.

Mr. Caywood's plans called for the pupils to make "saxophones" from soda straws. The pupils entered the activity with enthusiasm and soon had a wide variety of noise makers.

The plans then called for a discussion of the relation of pitch to length of air column. But when Mr. Caywood tried to initiate the discussion his voice was drowned out by various squeakings and tootlings. Only by shouting and by making a few threats did he obtain sufficient quiet for the discussion.

The reaction of Mr. Caywood's pupils was perfectly normal. They had made their saxophones and they wanted to use them. They felt little incentive to lay them aside in order to engage in a discussion. Mr. Caywood had given no consideration to the means by which he was to end one activity and begin the next. He had visualized the two separate activities either of which would be perfectly satisfactory alone but which conflicted when placed in the order he used them.

Had Mr. Caywood anticipated the problem he could have planned an adequate transition with little effort. He might have arranged to collect the straws before beginning the discussion. Or he might have used a more tightly controlled activity to follow the making of the saxophones.

Beginning teachers must be especially concerned about transitions because they have few resources on which to draw when problems begin to arise. Experienced teachers have usually learned by trial and error the procedures that succeed and those that fail. But for all this, it is not uncommon to see an experienced teacher ungracefully shouting at his pupils when a little forethought would have kept things going smoothly.

An unfortunate consequence of the failure to consider transitions is an increased dependence upon formal methods of teaching. A teacher may believe fully in the advantages of the free and informal classroom, and he may prepare plans and materials diligently. But when he finds himself with serious discipline problems, he mistakingly places the blame on the activities that give pupils freedom. He is apt to abandon all such activities and turn completely to formal teaching procedures.

If pupils can be brought into the planning process the problems of transitions are reduced. Pupils know exactly what they will be doing and they turn from one activity to the next with little direction from the teacher.

The transition from a tightly controlled activity to a freer one causes little difficulty. The pupils are already quiet and listen to directions calmly. The reverse process, changing from a free activity to a tightly controlled one, is more troublesome. The pupils are busy at their different tasks, or they have ended them and are busy with activities not called for in the plans. They are usually talking and there is a high noise level in the room. A teacher has difficulty projecting his voice above the hubbub.

There are several techniques for making this kind of transition. One commonly used procedure is to give directions for the second activity when giving directions for the first. For instance, pupils about to carry out a laboratory exercise may be told that they are to return to their seats as soon as they have finished in order to make diagrams of the apparatus used.

Another technique is to end an activity with another that introduces itself. The projection of the first slide of a set, or the blinking of the room lights in announcement of a film indicates that a new activity is about to start. Similarly, a teacher may hold up a sheaf of test papers or worksheets, thus announcing something new to do, and the pupils receive the papers as they come to their seats. A somewhat similar

technique calls for the teacher to write on the blackboard the directions for the new activity. Pupils who first notice the writing of the directions begin the new activity and the others soon follow suit.

An activity may be ended by sending pupils around the room to collect tools, materials, and waste. This signals the end of the activity and removes the causes for distraction. The technique is not always successful, because pupils sometimes argue about giving up the things they are working with.

A difficult transitional period occurs at the end of long tests, long reading assignments, and long writing assignments. Some pupils are certain to complete their tasks ahead of others. By keeping such tasks short, the time spread is reduced. When a wide spread is anticipated, the pupils who finish first can be given interesting things to do. They usually like to put away materials, take care of plants and animals, and arrange the bulletin board. Some prefer to work on their own special projects or read special books.

A transition that causes annoyance for many teachers is the one at the beginning of the period. Pupils enter the room talking loudly about their own affairs, teasing each other and sometimes scuffling. They may not cease these activities the instant the bell rings.

It is often well to begin classes with a tightly controlled activity such as a test, a worksheet to be filled out, or a sheet of printed directions. Discussions and directions given orally should rarely be used. Films, slides, and interesting demonstrations may serve to initiate a period when pupils are accustomed to settling down to work quickly.

The ending of a period may be as difficult as the beginning but teachers are apt to ignore the problem. Nonetheless it is a sign of poor planning when pupils stack their books several minutes before the end of the period, sit watching the clock, and jump the instant the bell rings. Plans should provide sufficient interesting activities to keep pupils busy until there is a signal to prepare for dismissal.

Planning assignments. The most valuable assignments are those in which boys and girls carry on at home science activities that seem important to them and that contribute to their general growth. Obviously, this type of assignment varies from pupil to pupil. One individual may benefit most by reading a specialized science book. Another may benefit most by working with his father on a model of a derrick. A third may benefit most by studying an ant hill.

Too frequently assignments require work of a stereotyped and unpleasant nature for which the pupils can see little purpose. Indeed, many assignments seem to be little more than "busy work" selected without thought of possible value to the pupils.

Commonly the assignment is a hurried order given as the dismissal bell rings, "Read pages 74 through 82 in your textbook." The purpose of such an assignment is not obvious. Is it made to give the pupils practice in reading? Are they only to acquaint themselves with the contents of the pages? Are they expected to master all the information on the pages?

Another common assignment of doubtful value is the order to write out the answers to the questions at the end of the chapter. Again the purpose of the assignment cannot be determined by either the pupils or an observer. Certainly boys and girls with high academic ability do not benefit from writing out the answers to such questions and it is an insult to ask them to do so. And pupils with very low academic ability cannot succeed at this type of work, so they do not benefit either.

Assignments used by master teachers provide flexibility for pupils of different interests and talents. Often these assignments are voluntary in nature. One pupil may choose to report on the content of certain pages in a supplementary textbook. Another may wish to look in reference books for answers to questions raised by the class. A third may volunteer to ask a specialist for information. A fourth may wish to try an experiment at home. Commonly pupils work together on such assignments.

A type of assignment that is little used but that has much promise calls for a repetition of or a continuation of work done in class.

Mr. Cole's eighth grade science class was about to study photography. Mr. Cole brought in photographic papers and the chemicals needed for developing them. The pupils mixed the solutions, darkened the room, and established a routine for the operations.

Each pupil placed some object, such as a paper clip or a leaf or a cut-out of opaque paper, on a sheet of photographic paper and exposed it to sun light for a few seconds. The pupils then took turns developing the silhouettes they had produced.

At the end of the period Mr. Cole explained where the pupils could buy paper and chemicals and how they could improvise materials to repeat the process at home. The next day all pupils, working either alone or with a friend, had repeated the experience, and some had tried to make prints from photographic negatives.

There are many other possible classroom activities that use materials easily procured by pupils and that are challenging enough to start the pupils working at home. Mr. Cole's record of one hundred percent participation will not generally be obtained, twenty five percent should be considered high, but this is work done because the

pupils want to do it, work for which they have given up television and movies and other things.

Whenever any assignment is made, whether it be required or voluntary, the pupils should understand exactly what is expected of them. If information is wanted, pupils should know precisely what they are to discover and why the assignment is important. If models are to be made or if experiments are to be tried out, pupils should have in mind exactly what they are to attempt. The assignments need not have been dictated by the teacher; they may have originated through group planning, but always they should be carefully defined. An assignment worth making is worth making painstakingly.

Using a lesson plan. A lesson plan is a guide but never a mandate. Its purpose is to give direction to the work of the pupils and to give the teacher a sense of security. But it should be altered if unexpected conditions arise.

Perhaps the pupils find one activity suggested by the plan so interesting that they wish to continue it. If the teacher feels that the additional time would be well spent he may allow the activity to run over the scheduled time and even to the end of the period. The displaced activities may then be worked into the next day's plans.

The pupils may show an interest that makes an activity assigned to the end of the plan more suitable for earlier presentation. A teacher should feel free to make the change. Spontaneous interest makes any activity more meaningful.

Sometimes pupils indicate an interest that suggests activities not written into the plan. Again the teacher should feel free to abandon his plan and utilize the new activities if this seems advantageous. Should the new avenue of work turn out to be less profitable than expected, he may return to his plan for the remainder of the period.

ANALYSES OF SOME SAMPLE LESSON PLANS

It may be helpful to examine a few lesson plans to see how the activities have been selected and organized. Some of these plans are for rather formal situations, some are for very free situations, and some are for situations in which there is a transition from formal to moderately free conditions.

A lesson plan for an earth science class is shown on page 345. The period opens with a report from two pupils who have kept a record of cloud formations since the last class period. This is followed by an interval during which the pupils, working alone, bring their individual weather records up to date. The teacher does not supervise the pupils

during this activity; they are free to consult the weather instruments and each other's records. The two pupils who will later put on a demonstration use this time to make final preparations.

The principal topic of the lesson is now introduced, previous work having been part of routine procedures. Two boys demonstrate the formation of fog, this activity bringing the class back together again as a single group.

Next comes a brief summary of pupil experiences with fogs, this discussion being led by the teacher. After a few contributions by the pupils the teacher makes a pertinent assignment—to read about the various types of fogs. It is assumed that he makes the assignment specific, perhaps in terms of the fogs described by the pupils. He also uses the opportunity to choose the cloud observers for the next twenty-four hours and to ask for volunteers to prepare another demonstration.

The pupils now begin working in pairs to familiarize themselves with dew point apparatus, the concepts thus developed being helpful in their reading about fogs. As pupils finish their work with the dew point apparatus they return to their seats and begin calculations that strengthen their concepts of dew point. If any time remains they begin their reading assignment.

An overview of the unit shows that the teacher has planned to dominate the room only during transitions and for the short discussion period. At all other times he is either at the rear of the room or moving about giving individual help and encouragement. He could even step from the room for several minutes without changing the program.

There is in this lesson considerable variation in the types of activities, and the types vary among large group, small group, and individual activities. No single activity is carried on for a long time but the period is not "choppy" because all the activities in the last part of the period are closely related.

Transitions are well taken care of, the two that might give difficulty —leading from the individual work on weather charts and leading from the group work with dew point apparatus—have been anticipated. To care for the first the plan utilizes curiosity in a demonstration presented by fellow pupils, and the second is cared for by the individualized work that is to be done as soon as the group work is finished.

The lesson is rather rigidly planned with few opportunities for the pupils to exercise initiative. It is the type of lesson that is effective in almost any situation in which the teacher has reasonable control of the pupils. It is suitable for lessons early in the year before a teacher has become well acquainted with his group. It does not, however, represent the ideal lesson towards which a teacher should be working.

On page 336 is a lesson plan for a chemistry class studying acids. At

DAILY LESSON PLAN

Class Earth science, Section I — Date 10/3
Unit Precipitation — Topic Formation of fog

Specific Objectives
to show relation of temperature and dew point
to show causes of fog
to become acquainted with various types of fog

Time	Activity
9:15-9:20	Cloud observers report on clouds of last 24 hours
9:20-9:25	Bring individual weather charts up-to-date
9:25-9:35	Demonstration (Jack and Don) of fog formation
9:35-9:40	Summary of experiences with fogs Assignment
9:40-9:55	Become familiar with dew-point apparatus in pairs *Use textbook*
9:55-10:05	Practice determining relative humidity from dew point data
Additional	Begin assignment

Assignment
Read about types of fog
Volunteers prepare demonstration on condensation nuclei
New cloud observers appointed

Materials	References
12 dew point apparatus 12 thermometers 6 bottles of ether	Pictures of fog for bulletin board Mimeograph sheets of dew point tables

the beginning of the period, probably as the pupils are settling down, a set of quiz papers is given back. Presumably there is some discussion of answers but the time allotted is short. Perhaps the answers were discussed immediately after the test was taken.

The principal work of the period begins with a review of tests for acids, with pupils demonstrating the techniques as they recall them. The information so reviewed is then applied immediately to tests of common foods by the pupils working in pairs. Upon completion of the tests, the pupils summarize their findings in their notebooks.

The period ends with an assignment of project work. A number of topics are listed and probably some pupils will suggest others. Some of the topics call for book research, some for experimental research, some for models or charts. Pupils may work alone or in pairs on the project of their choice.

Excepting the return of the quiz papers, activities change from large group to small group to individual, and back to large group again. The transition from small group work is taken care of by directing the pupils to summarize their results in their notebooks as soon as they complete testing the foods.

The weakest point in the lesson is the assignment. If the pupils do not work as rapidly as anticipated there will be no time for the assignment or else the assignment will be made hurriedly. Also, because the pupils will be completing work on their notebooks at various times it will be difficult to bring them all together for the assignment. It might be better to suggest that the pupils continue testing foods at home and delay the assignment of projects until the next lesson.

This particular lesson does not permit much opportunity for pupil initiative and independence of thinking. The assignment, however, leads to lessons that allow pupils to work on material of their own choosing and that gives them considerable latitude in their procedures.

The biology lesson plan on page 347 begins with reports by committee chairman of decisions made near the close of the previous period. After the reports, the committees meet again to plan their approach to certain experiments. Recorders list the materials needed and chairmen ask for volunteers to work after school assembling materials.

Committee work is interrupted by a film introduced without previous discussion. After the film the pupils recall various types of plant responses pictured in the film. If any time remains the pupils begin the preparation of a summary sheet for their learnings in their individual notebooks. The assignment is suggestive, not required, and made at the end of the discussion period.

The activities in this lesson vary from large group work, to small

DAILY LESSON PLAN

Class Biology, Section 2 Date 5/2

Unit Behavior Topic Responses of plants

Specific Objectives to begin group experiments on plant behavior
to become acquainted with some general responses of plants

Time	Activities
1:50-1:55	Group chairmen report on experiments each group has chosen
1:55-2:05	Planning sessions to determine materials needed by each group Recorders compile lists Request for volunteers to stay after school to collect materials
2:05-2:25	View film "Germination of Seeds"
2:25-2:35	Summarize plant responses, shown in film Discuss time-lapse photography if needed
Additional	Prepare summary sheet of plant responses for notebooks

Assignment: Volunteers stay to assemble materials for experiment
(optional) Begin experiment or field observations of plant responses

Materials	References
	Film—"Germination of Seeds"

group work and to individual work, to large group work, and if there is time, to individual work again. The teacher dominates the room for a few minutes during the discussion. The only difficult transition, at the end of the committee work, is provided for by beginning the film without discussion. A certain amount of pupil initiative is encouraged by the committees and the voluntary assignments. The film, however, greatly shortens the time when the pupils must be responsible for their own behavior.

The lesson plan for a physics class, page 349, illustrates the use of the problem approach during most of a period but with sufficient variation of activity to keep the pupils busy. The teacher presents the problem, "Will any kind of light make the radiometer turn?" The pupils are then asked to suggest different light sources that may be tested. In his plan the teacher has listed several possibilities to help in assembling sufficient materials for the experiments.

The pupils are then directed to divide themselves in groups of two or three members each depending upon the number of suggestions to be tested. During the next few minutes they assemble and put in operation the various light sources. They then test the effect of the different light sources on the radiometers.

When the tests are completed the pupils reconvene to summarize their discoveries. More questions may arise from the experiments and be discussed. If there is time, the teacher will demonstrate the effects of some of the light filters on sunlight to show that different rays exist. The pupils are now ready to recognize that the rays which turn the radiometer form a limited portion of the spectrum. Their reading will strengthen this concept. Optional assignments permit pupils to explore further the nature of infrared.

The activities change from large group to small group and back to large group. Physical activity is permitted in the middle and major portion of the period. The teacher dominates as a moderator during the two discussion periods and as a demonstrator during the last activity. He might minimize his role still further by using pupil secretaries to keep records on the blackboard and by using pupils as helpers with the demonstrations.

There might be control problems during the small group experiments as certain groups finish ahead of others or as some groups wait their turn for the use of the radiometers. However, pupils in physics classes are usually interested enough to watch the work of other groups.

The optional assignment is of the type that appeals to physics students. Several pupils might volunteer to present demonstrations. They would be aided by references to books which contain suggestions for such activities.

DAILY LESSON PLAN

Class Physics — Date 3/16

Unit Radiant energy — Topic Infrared radiation

Specific Objectives to discover radiation beyond the red end of spectrum
to discover some of the properties of infrared rays

Time	Activities
10:30-10:40	Demonstration of radiometer in sunlight Speculate on types of light that operate radiometer Plan experiments to test kinds of light Possible suggestions: Fluorescent lamp — Incandescent lamp Gas burner — Neon lamp Flash light — Argon lamp Arc lamp — Gas mantle lamp Burning wood — Electric hot plate
10:40-11:00	Groups of two or three test possibilities
11:00-11:10	Summary of results and discuss
11:10-11:20	Teacher demonstration of effects of various filters on behavior of radiometer. Introduce "infrared." Assignment
Additional	Groups begin planning experiments using filters

Assignment: Read about the nature of infrared
(optional) Plan demonstrations of effects of infrared radiation

Materials		References
Radiometers	Argon lamp	
Lamp cords	Gas burner	
Fluorescent lamp	Gas mantle burner	
Incandescent bulb	Electric hot plate	
Flashlight	Set of filters	
Neon lamp bulb		

Suggested activities

1. Observe a science lesson. Spot check the attention of the pupils at regular intervals. (This is best accomplished by several observers, each of whom studies a section of the class.) Plot the results as shown in figure 12. Analyze the lesson to determine which situations produce a high percentage of attention and which situations permit attention to lapse.

2. Observe a science lesson by an experienced teacher and note how he makes a transition from one activity to the next. Note also how he opens and closes his lesson. Which techniques are effective in terms of classroom control, and which could be improved?

3. Make a lesson plan that calls for three or more activities. Provide proper transition from one activity to the next so that classroom control is maintained.

4. Plan a lesson that is based on a full-period field trip. Give proper attention to such factors as attention, assignments, and the like. If necessary, reread pertinent sections of the chapter on field experiences.

Suggested readings

Brandwein, Paul F., Watson, F. G., and Blackwood, Paul E., *Teaching High School Science, A Book of Methods*, Harcourt, Brace, New York, 1958, pages 126-145.

Heiss, E. D., Obourn, E. S., and Hoffman, C. W., *Modern Science Teaching*, Macmillan, New York, 1950, pages 140-141.

Hunter, George W., *Science Teaching at Junior and Senior High School Levels*, American Book Company, New York, 1934.

Richardson, John S., *Science Teaching in Secondary Schools*, Prentice-Hall, Englewood Cliffs, N. J., 1957, Chapter eight.

UNIT PLANNING

chapter 14

Unit organization became an important factor in educational practice early in this century. Previously, the educational scene was dominated by the "recitation method" with its daily-ground-to-be-covered procedures. Unit organization seemed a possible antidote for the abuses of the daily recitation. It was designed to make more use of positive motivation and to give greater attention to individual differences.

Superficially, units in the science program have always appeared to be little more than blocks of subject matter. In consequence many teachers have the wrong impression of what a teaching unit is like, and they fail to take full advantage of its characteristics. A true teaching unit is as concerned with the means of presentation as with the subject matter involved. In other words, a teaching unit is composed of both method and content.

Unit organization makes two types of contributions to the educational process. First, it breaks up the year's work into sections small enough so that pupils can grasp the scope of any one of them during a brief overview. Most pupils work better on a series of short tasks than on a few large ones. They can grasp better the purpose of what they are doing. They can concentrate more intently for short periods and are spurred on by prospects of early completion of each task. They are stimulated by their more frequent successes.

The second type of contribution of unit organization stems from procedures used in developing a unit. There is an introductory phase during which pupils are shown the purpose of what they will be do-

ing and during which they are made ready for their tasks. This is followed by the presentation of new material. Finally, there is a concluding phase during which the material presented is made meaningful to the pupils.

Unit organization has had strong influence on modern teaching practice. At one time the use of teaching units was even called the "unit method," to distinguish it from the "recitation method," the "project method," and the "laboratory method." Today the distinction no longer exists and such techniques as recitation, project work and laboratory work may be called for in a unit plan. But the basic structure of the unit still remains a prominent feature in the educational scene.

THE STRUCTURE OF A TEACHING UNIT

Teaching units are organized on the premise that in order to learn pupils need more than mere exposure to subject matter. Accordingly, in a teaching unit there are introductory phases that prepare the pupils for the experiences that lie ahead of them, there is a main presentation during which the pupils have opportunities for meaningful experiences, and there are concluding phases during which the pupils organize and review the learnings they have acquired.

Thus a teaching unit has a structure of its own. It is neither a block of subject matter nor a series of independent lessons. Each lesson plays a role in the development of the unit. Under some circumstances a lesson may be part of the introductory phase or it may be devoted to the presentation of new experiences. Usually, however, a single lesson has more than one function, perhaps getting the pupils ready for a new experience, then presenting the experience, and finally helping the pupils assimilate the learnings. There is no stereotyped pattern for the development of a teaching unit; everything depends upon the nature of the subject matter, the background of the pupils, and the conditions under which the unit is taught.

The elements of a teaching unit. The teaching unit as developed early in this century has the following elements:

1. Motivation
2. Overview
3. Inventory of background
4. Presentation of new experiences
5. Organization of learnings
6. Summarization
7. Drill
8. Review
9. Evaluation

It is important to realize that these elements of a teaching unit need not be used in the above order. Review and drill may be used through-

out a unit, not just near the end. Sometimes an inventory of pupil backgrounds serves little purpose. Motivation may need attention several times.

The motivational phase. Pupils need a purpose for what they do—not a purpose dictated by the teacher, but a purpose they themselves recognize. The motivational phase is designed to help pupils establish *their own purposes for what they will be doing as the unit progresses.*

The motivational aspect of planning is often misunderstood, as is described in chapter three. Too often teachers act on the assumption that motivation can be applied from without. They set up their own purposes for the unit, usually without reference to the needs of pupils, and try either to force these purposes upon the pupils or to "sell" them to pupils with a variety of clever tricks and devices. A later section of this chapter will describe some specific techniques for handling the motivation period.

The overview. An overview of a unit helps pupils see the scope of the material with which they will be dealing. They then can look ahead and plan their procedures accordingly. Obviously, the overview is of great importance in teacher-pupil planned units. The overview must be complete before plans can be made. However, the overview need not be made by the teacher; the pupils themselves can define the scope of their work and prepare the overview, not necessarily in the formal sense but perhaps as they are defining the problems they intend to solve.

In teacher-dominated units the complete overview need not be given at the beginning. It is often wise to break the presentations into segments and precede each with a correspondingly limited overview.

The inventory of experience backgrounds. *"Start with pupils where* they are" is a precept of modern education. It is of special importance in science teaching because so many science understandings depend upon the experience backgrounds of the pupils.

An inventory of such experiences as are pertinent to a unit is useful in pointing out things that need not be repeated and that can be depended upon during discussions. It also shows lacks on the part of one or more pupils who will then need special attention.

The presentation of new experiences. Everything in a teaching unit is centered about the presentation of new experiences. All else is either a preparation or a follow-up for this phase of the unit.

Experiences presented may be either direct or vicarious. In general, firsthand experiences are more profitable because they are so well remembered, because all pupils can benefit from them, and because

the resulting learnings tend to be more accurate than those derived through some medium of communication. However, books, films, and other sources of vicarious experiences are valuable when pupils have backgrounds adequate for interpreting them.

In most units, a judicious balance between direct and vicarious experiences is to be desired. Direct experiences introduced early in a unit provide a background helpful in interpretation of vicarious experiences introduced later. Direct experiences also encourage all pupils to take an active part in the work of the unit and thus benefit by the early introduction of such experiences.

There is no fixed rule for the presentation of new experiences. Usually it is wise to present a few in each lesson rather than to concentrate a large number in a few lessons. There should always remain, of course, a few lessons devoted to review or organization or some other type of activity.

Organization and summarization are an integral part of the learning process, and provision for them should be included in every unit. The chart that these pupils are making summarizes much that they have learned about blood. Later the chart will help other pupils review the work of the unit.

The organizational phase. Good teaching practice specifies that there should be opportunities for pupils to bring their learnings together in some form that shows relationships. Teachers commonly decide upon the pattern for such organization and they make sure that pupils

recognize the pattern by providing study guides. Some teachers depend upon the organization given in the textbook.

However, in the teaching unit there should be provision for pupils to develop their own pattern of organization occasionally. This gives them a more active role in the process and is more effective in producing understandings. The pattern that results may not be conventional but it will be meaningful to the pupils.

Organizational activities are commonly verbal. Most written reports are summaries. Oral summaries are frequently used, often to help in the preparation of written reports. However, organizational activities need not be verbal. Many projects are in effect non-verbal reports. Their preparation involves careful organization.

Summarization. Summarization is an integral part of the learning process and is given an important place in the teaching unit. However, summarization is too often provided by the text and the teacher. Pupils should be given opportunities to carry out this activity for themselves.

Summarization is needed near the close of a unit to bring together all the learnings. Summarization is also desirable at intervals during the progress of a unit. Some teachers plan to end each day's lesson with some type of summarization activity.

Organization and summary commonly go hand in hand. As soon as a pattern of organization has been developed, learnings may be summarized according to this pattern. Sometimes from the summary a pattern of organization becomes evident.

Review and drill. If there is learning, there is certain to be forgetting. As soon as pupils cease to use the facts or skills they have learned they begin to forget them. A review is in effect a reteaching; drill is intensive and prolonged review. Whenever learnings are considered important enough for pupils to remember, review and sometimes drill must be provided.

Reviews are commonly verbal but need not be so. There are more effective ways to recall learnings. A learning experience repeated, in shortened form or with sufficient variation to hold interest, makes one of the best forms of review. Exhibits of collections, posters, and the like are commonly effective reviews.

Evaluation. Evaluation in the teaching sense is self-evaluation, provided to help pupils discover what they have achieved and what they have failed to grasp. This type of evaluation should come well before the end of a unit so that pupils can remedy their deficiencies.

Numerous short tests given throughout a unit help with self-evalua-

tion. They also serve as review and drill when constructed with these functions in mind. It is usually good practice to give two or three short written tests a week.

Because verbal tests measure only limited outcomes, other forms of self-evaluation should also be provided. Whenever possible, performance tests should be used. Individual interviews, during which pupils demonstrate and explain, are especially effective.

Self-checking devices are helpful. Electric question boards make self-evaluation seem like a game. Science crossword puzzles are often used for vocabulary testing. Picture quizzes and the like are effective.

The final test of a unit serves only to provide a grade and to help a teacher evaluate his own teaching effectiveness. It should be constructed with these purposes in mind.

SELECTING THE CONTENT FOR A UNIT

The success or failure of a unit is determined in large part by the nature of its content. Some material lends itself to good teaching practices; some does not. Criteria for a good unit are listed below:

1. It should be possible to base each unit upon many direct, individualized experience activities.
2. A unit should deal chiefly with work that has not been done before.
3. The range of materials included in a unit should be sufficiently wide to interest all pupils.
4. It should be possible for the more capable pupils to extend the unit beyond the limits suggested.
5. The unit should have many direct applications to the immediate lives of the pupils.
6. The unit should anticipate some of the future needs of pupils.
7. A unit should be part of a sequence that permits growth from year to year.[1]

The choice of subject may be dictated in part by the program outlined in a course of study or a textbook. However, all such programs can be modified to meet specific situations; even when the content is mandatory, the pattern for organization is not. The nature of a unit can therefore be dependent upon a number of important factors.

The need for limitation of content. All too commonly teachers plan units entitled "Electricity" and "Reproduction." These topics are far too broad to be given adequate treatment in single units. To attempt to use them encourages superficiality of thinking and may produce incorrect concepts because of over-simplification. Many pupils become

[1] From *Science 7-8-9*, New York State Education Department, Albany, New York, 1956.

confused and discouraged by the many subdivisions and the possible ramifications.

More suitable units can be built around such limited topics as "Electricity in the home" and "Starting plants without seeds." Pupils are able to grasp the scope of these units in one brief overview. They can keep the major problems and methods of attack in mind throughout the unit. They have opportunities to discover the details upon which the more limited generalizations are based.

Following are some titles of successful units. The scope is self-evident from the titles.

1. How our homes are heated
2. Hard and soft water
3. Instruments of the school orchestra
4. How our bodies are controlled
5. Plainville's water supply
6. Developing new breeds of animals
7. Vacuum tubes and their uses
8. Plants in autumn
9. Weather instruments at the airport
10. Geology of Danby State Park

The importance of familiar materials. Units based on familiar materials are generally more successful than units based on remote and strange materials. Pupils have an experience background on which new understandings can be built. They recognize the significance of the problems that are raised. They appreciate better the references that are made during the progress of the unit and they understand better the applications that are made.

Whenever possible, a unit should be built around local features. A unit on the local water supply is generally better than a unit on water supplies in general. A unit on glaciers can have real significance in Tacoma, Washington, where the glaciers on Mt. Rainier can be seen each clear day, but a unit on limestone formation would be of more significance in Miami, Florida.

A unit based on local and familiar materials need not be confined to these narrow limits. As individual pupils demonstrate interest and adequate background for more extended coverage they may be given special assignments.

The need for suitable experiences. Learning is not a "pouring in" process, but a gradual process that comes about as a result of experiences. Unit planning, therefore, is largely a matter of deciding upon suitable experiences that may be provided for pupils. The content of the unit should be determined in large part by the availability of suitable activities for providing the experiences needed.

The best topics for units permit a variety of field trips, experiments, demonstrations and projects. All these experiences can then be amplified by available books, films, and slides. Topics that must depend upon lectures and textbook readings for basic understandings are not well suited for young people with limited experience backgrounds.

Consideration for general education objectives. The general education objectives of the science program, as distinct from subject matter objectives, are those that bring about desirable changes in the ways of thinking and actions of boys and girls. General objectives demand situations in which pupils have opportunities to grow. Lectures, textbook recitations, and dictated notebook exercises do little to improve the personalities of young people. Teacher-pupil planning, small and large group problem-solving situations, pupil presentations of subject matter, and projects of all kinds are essential in working towards general objectives. Content should be chosen to permit the use of such activities.

WRITING UNIT PLANS

Following the determination of content and the writing of appropriate objectives comes the selection and organization of learning activities. The teacher who has a card file of suggestions for activities may now turn to it for help in this critical phase of planning.

Using a prepared form. A prepared form is an important time saver in any type of planning. Of various forms that have been developed only two are illustrated here. The first is relatively simple for beginning teachers to understand and prepare. The second has certain advantages of flexibility that make it of great service to experienced teachers.

The simpler of the two forms is shown on pages 360-361. The activities and their expected outcomes are arranged in parallel columns. In this form the activities are listed in the left hand column and the outcomes in the right; a variant of this form reverses the two columns. The activities are listed in the sequence in which they are to be presented but minor modifications can be made as the unit progresses. This type of form makes no provision for the several phases of the teaching unit. A teacher must keep in mind as he plans his needs for organizational activities, review activities and the like.

Certain cautions must be observed when using this form. The parallel arrangement encourages a tendency to write a single activity followed by a major outcome. This encourages superficiality and unwarranted generalization. The expected outcomes should be limited

in scope and each should be attended by a sufficient number of learning experiences to insure understanding. Commonly, these activities should represent different approaches to the same point.

The major disadvantage of this form is its relative inflexibility. The schedule is determined in advance and the teacher is more or less committed to follow it. Any major alterations necessitate rewriting the entire plan. In consequence unexpected events and new directions of interest cannot be utilized conveniently.

An entirely different form, shown on pages 362-363, is a plan for what is known as a resource unit. The plan does not specify what is to be done nor the order in which presentations are to be made. Instead it lists in rich variety activities that may be used as conditions dictate. It is not a teaching plan but a true resource to which teachers may refer during daily lesson planning.

The major advantage of the resource unit is its flexibility. The first lesson of a unit may reveal unexpected conditions. Pupils may have stronger or weaker backgrounds than anticipated. They may display unusual interests. They may have negative attitudes towards the subject chosen or the presentations used.

The resource unit does not commit a teacher to a predetermined organization. When planning the second lesson of a unit he may turn to the resource unit for suggestions that enable him to fit this plan to the interests and abilities displayed during the first lesson. The third lesson can be built in accordance with conditions discovered during the teaching of the second lesson. At any time the unit may be directed into a new channel if this seems advisable.

A minor advantage of the resource unit, but one not to be ignored, is its long useful life. Any plan that specifies procedures and schedules should be rewritten before each reuse to fit it to changed conditions. But revision of the resource unit is no more than the addition of new suggestions as these are encountered and the crossing out of suggestions found impractical. Rewriting is needed only when the plan becomes cluttered to the point of confusion.

For many beginning teachers the resource unit may be considered as too flexible. The daily plans can deviate too widely. The class may ramble. The unit may go on indefinitely. To use a resource unit wisely a teacher must have in mind at all times the general scope of his unit so that deviations do not go too far astray, so that important phases are not ignored, and so that the unit is brought to a close in a reasonable time.

The two forms shown on pages 360-363 may be duplicated on standard notebook paper and punched to fit two-ring or three-ring notebook covers. It is helpful to punch the sheets so that the pairs face

TWO PAGES OF A UNIT PLAN IN GENERAL BIOLOGY *

UNIT 6 How our bodies are controlled

Date February 6 Approximate Time Three weeks

Principles towards which the unit is leading:

Many of our activities are controlled by our nervous systems

We can consciously control some acts; others we cannot control

Some of our actions are controlled in whole or in part by internal secretions

Activity	*Expected outcome*
1. Demonstration: Difficulty of catching dollar bill dropped between fingers	Awaken interest in mechanics of body
2. Class experiment: Pupils working in pairs repeat above with strips of paper	
3. Trace path of nervous impulse on chart of nervous system	Understanding of paths of impulses
4. Pupils make similar chart for notebooks	
5. Demonstration: Class in circle, each pupil touches pupil ahead as soon as he feels touch. Time elapsed divided by number of pupils gives reaction time	Understanding of reaction time and its importance
6. Discussion: Reaction time in sports and in driving autos and planes	
7. Special project: Make a reaction timer and test others	
8. Special project: Work out time and distance needed to stop cars at different speeds	
9. Demonstration: Electric stimulus of nerve in freshly dissected frog leg	Recognition of similarity between nervous impulse and electric current
10. Experiment: Pupils test own reactions to electric stimulus	

Activity	Expected outcome
11. Special project: Read in physiology book about nature of nervous impulse	
12. Special project: Test earthworms for reaction to electricity	
13. Class experiment with knee-jerk reflex, eyelid reflex, iris reflex, balancing reflex	Understanding of paths involved in certain special cases
14. Assigned reading: Pages 102-113 in textbooks	
15. Home problems: Test dogs for vibrassa-eyelid reflex and for scratching reflex. Test baby for grasping reflex	
16. Film: "The Nervous System" (EBF)	Summarize and organize understandings and lead into study of nerve centers
17. Chart of brain	Location of important centers
18. Assigned reading: Pages 113-131 of textbook	
19. Special projects: Make chart of human brain and of other animals for comparison. Dissect out brain of cat or rabbit. Compare brain capacity of different animals using sand in school collection of skulls. Read about experiments on the brain. Read about brain surgery	
20. Class experiment: Pupils practice with mirror writing	Understand how motor skills are learned
21. Home project: Continue practice with mirror writing, keeping records of time and results	
22. Discussion: Development of motor skills such as piano playing, auto driving, and so on	

* Other pages of the plan list additional activities and possible outcomes. The last page also includes test items.

RESOURCE UNIT PLAN

Title Static electricity — Time allotted 2 weeks

Principles toward which the unit is leading	Bodies may be given electrical charges There are two types of charges Charging bodies gives them energy Bodies attract or repel each other depending on charges A spark is caused when charges jump thru' the air
Former experiences common to all pupils	Sparks caused by scuffing feet on a rug Sparks when combing hair or petting cats Shock when leaving automobile Static on radio Lightning
Firsthand experiences Experiments	Rub different objects and test for charges Rub paper with different fabrics and put on wall Dancing paper dolls; action of paper fringe Floating bathtub toy; attraction of ping pong ball Behavior of two charged balloons, strips of paper, pith balls, fringed paper, pivoted rubber rods Reaction of unlike charged bodies—pivoted rubber and glass rods, charged bottle and balloons, charged pith balls and charged rods, etc. Production of sparks by brushing paper, balloons, etc. Lighting of fluorescent and neon lamps by charges Discharging sparks near a radio to make static Use home made electrophorus and charge metal cans

Demonstrations	*Gold leaf electroscope*
	Static electricity machine
	Leyden jar
Field trips	To transformer station to see lightning arrestors
Home problems	Test various plastics for charges
	Brush hair or pet cats in dark
	Produce sparks near A.M., F.M. radios and television
Reference books	Text: pages 136 to 182
	Morgan: *Things a boy can do with electricity*
	Zim: *Lightning and thunder*
Films, slides pictures	Thunder and lightning
	Folder of clippings of pictures of lightning
	Make charts showing distribution of charges on materials used in experiments
Summarization activities	Make chart showing how lightning is produced
	Make a model showing how lightning rods operate
	Make model or chart showing safety in thunderstorm

each other and are both visible when the notebook is open. The reverse side of each sheet may be used for test questions.

Planning the motivational phase. The lesson plan shown on page 360 uses a simple trick to puzzle pupils, first as a demonstration to capture attention and then as a general activity to make sure each pupil recognizes his own strange limitation, and is puzzled by it. The in-

"Oh! This is going to be fun!"

"I'm sure it will be, Janet. Let's start right away by looking at these lenses."

Should pupils have an insufficient background, a complete overview at the beginning of a unit might be meaningless. It may be better in such a case to begin work on a minor problem out of which pupils develop experiences suitable for appreciating an overview of the major body of the unit.

Mr. Pettingill opened a unit on stream erosion with a field trip to a nearby stream to study the way running water erodes stream banks at a curve. The pupils made sketches of their observations.

Back in the classroom the pupils speculated about the differences between the inside and outside banks. Mr. Pettingill directed the pupils to their textbooks for authoritative answers to their questions.

The following day pupils came to class with additional questions about other aspects of stream erosion they had discovered in their textbooks. Mr. Pettingill helped them itemize and organize these questions on the blackboard. The resulting list served as an overview for the material that would be studied in the unit.

Whenever pupils help outline the scope of a unit in the above fashion the function of the overview is successful.

Preparing to inventory the experience backgrounds of pupils.

"How many of you have seen kittens being born? Calves? Puppies? How many of you have seen chickens hatching? How many have watched frog eggs develop?"

These were the questions Mr. Brown asked of his biology class at the beginning of a unit on reproduction. From the answers he knew fairly well what the background of his pupils might be and where he would need to start in developing his unit.

Commonly all that a teacher need to find out from his pupils are the answers to a few questions. Sometimes a brief discussion of an introductory demonstration or topic of immediate interest reveals the extent of the knowledge of pupils. A teacher must be cautious in drawing conclusions, however, because a few vociferous youngsters often give the erroneous impression that an entire group has certain experiences or understandings.

Written preview tests may be used occasionally, providing these are interesting. Long, detailed preview tests may discourage pupils who do not feel secure in the science program.

Many experiences can be taken for granted. By the time boys and girls enter the secondary school they have shared such common experi-

ences as lighting matches, operating electric switches, and boiling water. In a rural community all pupils will have seen seeds being planted and fertilizer spread on fields. In a coastal community they will have noticed the changes in tides and the appearance of a ship as it approaches over the horizon.

In addition to out-of-school experiences pupils will have shared a number of classroom experiences, especially in systems that use a uniform science program. In some schools a seventh grade teacher can be certain that all of his pupils will have at some time connected electric lamps and dry cells during their years in the elementary school. Sometimes a chemistry teacher may be certain that his pupils watched a demonstration of electroplating in the ninth grade.

The preparation of an inventory can be of much help during planning in eliminating needless repetition of experiences and establishing a foundation upon which to build. The resource form shown on pages 362-363 has a section on which this inventory may be made.

Planning firsthand experiences. A teacher's primary concern in planning a science unit is the collection of an adequate number of suggestions for field work and for classroom experiments. If enough of these suggestions can be provided the unit will probably be successful. It is relatively easy to select needed demonstrations and to find books, films, and pictures to amplify the unit.

Special attention should be given to the possibilities for individual experimentation. These are much more numerous than one may suspect, if one is thinking in terms of traditional college laboratory exercises. Popularized science books are filled with countless suggestions for experiments that require only simple materials and easy techniques.

Demonstrations have a place in the science program but they have serious limitations that make them inferior to individualized experiments and field work. They should be used when neither of these two is practical.

Field work, which provides some of the most valuable of teaching situations, is apt to be neglected unless during planning there are deliberate efforts to search for specific possibilities. Traditional science teaching, particularly in the physical sciences, has so neglected field work that possibilities do not suggest themselves and must be searched for. Nonetheless it is difficult to conceive of a unit which permits no field work because of the nature of its content.

Homework is usually thought of in terms of reading and the preparation of reports or other written papers. Homework in terms of firsthand experiences has never been given much recognition. And yet there are endless things pupils can do outside school hours to amplify

their firsthand experience backgrounds. Each unit plan should contain numbers of suggestions for these activities to be assigned either as required or as permissive work. The resource unit plan form shown on pages 362-363 has a special section for writing these suggestions.

Using books, films, and other audio-visual aids. Books, films and other audio-visual aids provide many learnings that cannot be gained through firsthand experiences in the usual school situation. These sources of vicarious experiences should be used as freely as possible but always with consideration for their limitations. Pupils who do not read well or who have limited experience backgrounds should not be penalized by unwarranted emphasis upon sources of vicarious experiences.

When books, films, slides, pictures, models and film strips are used to supplement firsthand experiences, the latter will help provide the background needed for proper interpretation of the former. In addition, pupils who do not gain much from the former type of activities, are not discouraged at the outset; instead they find activities that appeal to them and challenge them. An organization that puts vicarious experiences in a supplementary role is always a wise one. There are occasions when books and films may be employed in other fashions, especially when a group of pupils are academically talented, but the presentation should be carefully thought through in advance.

Books requiring different levels of reading ability should be listed in the unit plan. These may include books written for young children and books written for college students, since the range in reading levels of high school pupils is great.

First attention should be given to the books kept in the science classroom. These are always available and are therefore most useful. A brief survey of the school library and the community libraries will give the names of books pupils can borrow. If there is space, the titles of suitable books that are not available may be listed to serve as suggestions when library requests are presented.

Films and filmstrips available in the school collection should be listed. Rental films may be listed if there are opportunities to obtain them. Free and inexpensive materials loaned by various agencies should be listed so that they may be ordered.

Providing summarization activities. Pupils need opportunities to bring together their learnings, organize them, and view them as part of a complete picture. Various types of projects serve excellently for this purpose. Among the projects that may be used are charts, models, collections, exhibits, and paintings. Dramatization can play an important role with plays, assembly programs, radio presentations and mock television programs. Notebook and scrapbook exercises are help-

ful. The results of class work may be written up for the school and local newspapers.

A wide range of types of activities is desirable. There should be suggestions to suit different interests and different talents. There should be activities that can be carried out by the class working as a whole, by small groups working independently, and by individuals.

Suggestions for project work may be difficult to classify. Many projects require collecting information as well as organizing it. It matters little where these suggestions are placed in the final plan, as long as the potentialities of each are fully utilized.

To culminate a unit on electricity a physics class prepared an exhibit depicting some of the major developments in the history of that area of science. On a table were displayed miniature models of some of the devices that brought about early discoveries or made these discoveries useful. Behind the tables a frieze gave names, dates, places and pictures to supplement the exhibits.

Summarization is usually thought of as conducted by the teacher. This need not be so. Pupils often are able to summarize their learnings with a little help from the teacher.

Near the close of a seventh grade unit on the uses of water, Mrs. Blair divided her class into six groups, each of which was directed to prepare a summary of the work done in one of the major areas of the unit—water power, drinking water, water for recreation, and so on.

The pupils met, used their notebooks and textbooks for reference, and prepared summary outlines. The class then reconvened, the summaries were discussed briefly, and given to Mrs. Blair. She had the summaries duplicated so that each pupil could have a copy.

Planning for review and drill. Needs for review and drill cannot well be determined in advance. Pupils may grasp desired content quickly, or they may be very slow. The best form of review and drill is reteaching. From the list of suggestions for demonstrations and experiments may be selected some that were unused earlier in the unit; when presented they review learnings often in a very interesting way.

The pupils in Mr. Jordan's physics class had constructed step-down transformers by winding coils of wire on large nails. Though these transformers were inefficient they could be used to make flashlight lamps glow.

A few days later Mr. Jordan placed a socket containing a flashlight lamp on his demonstration table. Immediately it began to glow.

The pupils were mystified at first but after noting that the lamp glowed only when placed in one spot on the desk, they recalled their laboratory

work and solved the puzzle. Taped to the bottom of the socket was an inconspicuous coil of wire. Underneath the table top was another coil connected to a source of A.C. current.

Preparing for evaluation. Excellent test items may suggest themselves during the preparation of a resource unit. If these questions are written out immediately they will be available at any time during the teaching of the unit. If they are not written out, they may be forgotten or recalled with difficulty.

If the resource unit form described in the previous section is used, the test items may be written on the reverse of the second sheet. Additional pages may be added if needed. Amendments and additions may be added at any time.

It is convenient to have a selection of test items immediately available whenever a test is to be constructed. Sometimes one is in a hurry and sometimes one is tired. It is much easier to select suitable items for a test than it is to formulate them.

Greater justice is done to pupils when test items are written out before the unit is taught. The items may be written with greater care, or, if not, there is an opportunity to revise them. Special words used in the questions are introduced carefully and drilled upon. And the test items are written with the over-all view of the unit in mind.

SPECIAL UNITS FOR SPECIAL PURPOSES

During the past half century, several unusual and interesting teaching procedures were proposed, tried out, and abandoned. Each type had certain strengths but each also had its weaknesses. Too much was expected of it, and when it failed, it was discarded completely. Nevertheless, these procedures have important values when used with care and understanding. Each type appeals to different personalities. Each changes the emphasis in a program, adds variety, and broadens the appeal of the science program to young people.

The major weakness of most of these special teaching procedures was their *inflexibility*. Once embarked upon, a set of plans had to be continued through to the end or abandoned entirely. There was little or no opportunity to adjust the plans as new conditions arose.

When using these special procedures in the science program it is important to remember this inflexibility. The units should be kept short and limited in scope. No matter how strongly the procedures may appeal to an adult, there is no guarantee that a group of adolescents will be challenged by them for more than a few days at a time.

Contract units. During the 1920's there were several experiments with completely individualized instruction. Generally, all these plans established subject matter goals and then set the pupils working towards these goals as rapidly as each could progress. These plans emphasized subject matter achievement almost to the exclusion of everything else. They succeeded best with those pupils who enjoy working alone on academic tasks. Other pupils did not fare so well.

One of the individualized programs became rather famous as the so-called "contract plan." Each pupil was given a list of a set of tasks. He could "contract" to do a minimum number of these tasks for a satisfactory but minimum grade. Or he could contract to do a greater number of tasks for a higher grade.

The contract plan appeals to certain types of pupils and it is a welcome change from conventional procedures. A short contract unit often gives excellent results.

Miss Birdsall was doing her cadet teaching in a system that allowed her to experiment with almost any procedure she wished. One day, her supervisor stopped to see the principal of the school.

"What kind of a girl did you send me anyway?" the principal asked bluntly.

Fearing that Miss Birdsall had committed some serious faux-pas, the supervisor asked what she had done.

"She's not in any trouble," the principal explained. "But when I came home the other night at eleven o'clock my son was still working on his science. The next night he worked until after ten. Ordinarily, he never does any kind of homework unless I make him. So I asked him what he was doing. He told me he was trying to finish his science contract. I thought contracts went out years ago."

A contract unit used for science should be short, perhaps five or six days at the maximum. It should be based on activities that pupils can carry out successfully by themselves, at home, during study periods, and in the library. Book research, simple home experiments, and field work lend themselves best to the contract plan.

Pages 372-373 show the duplicated sheet given to the pupils of four eighth grade science sections about to make a study of solutions.

Following a review of test papers that culminated the preceding unit, Mr. Axtell initiated a discussion of the meaning of a contract. He referred to contracts used in the construction of a school or office building. The pupils knew that a construction company can contract to build either a large building or a small building, and that the remuneration varies in each case. Mr. Axtell told about the time clause, which sets the limits within

A CONTRACT UNIT

Common solutions

Read through the following items and check those that you would like to do. Then decide what grade you would like to contract for. Grades will be given as follows:

D—The starred items plus one more from each group
C—The starred items plus two more from each group
B—The starred items plus three more from each group
A—The starred items plus four more from each group

Discuss your choice with your teacher and then sign your name in the proper place on the other side of this sheet.

* Prepare a title page for the section on solutions in your notebook.
* Introduce your unit with a description of what a solution is.
* Write an article telling why solutions are important to us.

Group one

* Learn how to use filter paper to filter liquids. Make a diagram for your notebook. Filter the mixture of muddy water and ink your teacher will give you. Describe your results.

1. By *experiment discover ten substances that dissolve rapidly in* water and ten substances that dissolve slowly or not at all.
2. Filter tea, coffee, milk, cocoa and six other common liquids. Describe what happens in each case.
3. Write an article on the nature of ocean water. Illustrate it with a graph showing the composition of ocean water.
4. Explain what "hard" water is and how it becomes hard.
5. Make up an *experiment to show whether heat affects the rate* with which something dissolves. Write up the experiment.
6. Find out how food becomes dissolved in our bloodstream.
7. Experiment to find out whether salt dissolved in water changes the boiling temperature of the water.
8. Set up an experiment to show how minerals get into plant roots.
9. Show that substances dissolved in water may change the density of the water.

Group two

* Evaporate the water from a solution of common table salt. Describe in your notebook what happens.

1. Write an illustrated account of the way sugar is prepared from sugar cane or sugar beets.
2. Find out how much mineral is dissolved in a gallon of tap water by evaporating the water.
3. Explain why rain water is "soft."
4. Tell how table salt mined from the earth can be purified.
5. Talk with a plumber about the problems caused by hard water in hot water systems. Write up your interview.
6. Prepare some distilled water and write up the process in your notebook. List some uses of distilled water.
7. Read about the playa lakes of the Great Basin west of the Rocky Mountains. Tell how they are formed and what happens in them.
8. Tell how early settlers prepared potassium hydroxide (lye).

Group three

* Read about crystals and the way they are formed. Write up your findings in your notebook. Draw some crystal forms.

1. Make some sugar or copper sulfate crystals.
2. Tell how stalagmites and stalactites are formed.
3. Make a "crystal garden."
4. Carve from soap or a potato the shapes of some natural crystals such as quartz.
5. Show how to "frost" glass with epsom salt.
6. Tell how crystals are used in industry.
7. Make a collection of sedimentary rocks made of materials cemented together by chemicals crystallized from water.
8. Make some candied orange peel.
9. Tell how petrified wood is formed.

This work is to be done at the end of the fifth period after the contract is signed. Extension will be granted in case of sickness. Extra credit will be given for superior work and additional work.

______________	______________________
(Date)	(Pupil's signature)
______________	______________________
(Grade contracted for)	(Teacher's signature)

which a job must be completed and which penalizes a builder who does not complete his work on time. He also mentioned the possibilities for bonuses if construction is finished early or if superior work is done.

Mr. Axtell proposed that contracts be used in the study of the next unit. The pupils were excited about the prospect and looked over the sheets of possible activities eagerly. Mr. Axtell directed the pupils to read each item carefully and check the ones each thought he would like to do. On the basis of the check marks each pupil determined the contract he would sign for. Mr. Axtell advised each pupil personally if there seemed any question about how much to contract for. Not many pupils aimed too high and none underrated his ability.

For the first two days all work was done individually in class time. On the third day, Mr. Axtell presented a demonstration near the end of the period. On the fourth day, he used part of the period for a discussion of results and a report of some special projects. On the fifth day he gave a culminating test during the last half of the period.

Most of the pupils completed their contracts on time. A few completed them beforehand and were encouraged to do additional tasks for bonus points. A few pupils did not finish on time and had to stay in detention room to make up their work.

Teacher-pupil planned units. It is highly desirable to have pupils participate in the planning of science work. They understand much better the purpose of what they are doing and they benefit in many ways from the experience with cooperative planning.

It must never be forgotten, however, that pupils are not trained in educational psychology nor in the special methods of science teaching. They cannot be expected to do planning that is equivalent to what a teacher can do. They will neglect areas and procedures of which they know nothing. They may select problems that are too big for solution. And they will greatly overestimate their attention span.

The teacher must give constant attention to the planning process. It is usually well for him to plan beforehand in complete detail the unit suggested to the pupils. He is thus able to use his plans as a starting point and as a reserve of constructive suggestions should the imaginations of the pupils fail.

Limited topics are best for teacher-pupil planned units. Pupils grasp the over-all development of the unit better. Mistakes in estimating pupil interest and attention span are less damaging. It is also well to choose subjects that can be treated through conventional methods. Pupils understand how to obtain information from books, but they may have difficulty in setting up original experiments and in doing field research.

The original Morrisonian Unit of the 1920's, although teacher dominated, can be adapted excellently to teacher-pupil planning. The Morrisonian Unit was divided into five steps:

1. Exploration (determination of pupil background)
2. Presentation (overview of the unit)
3. Assimilation (collection of information)
4. Organization (development of understandings)
5. Recitation (verbalization of understandings and applications)

The same five steps are desirable in the teacher-pupil planned unit but the emphasis is shifted to include increased opportunities for pupil initiative. The first step of the planning process may be given over to a free discussion of a problem set up by the teacher. This introductory problem must be selected with considerable care in order that the pupils will accept it as their own. It must appeal to their imaginations, lie within their experience background, and lead naturally into a number of sub-problems which the pupils can recognize without help.

The second step, which usually intergrades with the first, is the planning period proper, during which the pupils define precisely the problems and the procedures they expect to use in their solution. As planning proceeds the pupils gain an overview of the unit, just as the beginning discussion reveals their experience background.

The third step, like that in the original Morrisonian unit, is one in which pupils gather information. This they may do by experimentation, by field work and by reference to books. The fourth, or organizational step, is similar to the original plan but is modified to the extent that pupils organize their information for presentation to each other rather than in a form dictated by the teacher. The fifth period of the teacher-pupil planned unit is similar to the original recitation period except that its purpose is the sharing of experiences, rather than evaluation. Pupils should use demonstrations and exhibits of their work more commonly than strictly verbal reports.

Some of the more exciting teacher-pupil planned units have dealt with such subjects as "What makes us tick?"—a unit on human behavior. Pupils are greatly interested in themselves and how they look to others. They attack such units vigorously. However, much skill is needed to keep these units within bounds. Without careful guidance, class time is spent in wild speculations, in reading sensational literature, and in discussions of morbid aspects of the subjects.

Teacher-pupil planned units need not differ radically from other units in a science program. Perhaps for the first few attempts at this type of teaching it is wise to be somewhat conventional. Later, as pupils demonstrate their readiness to accept responsibilities, they can be given greater independence.

Mr. Dewey's first experience with a teacher-pupil planned unit thoroughly convinced him of its feasibility. He chose the unit "Iron and steel," because he could visualize his chemistry classes doing profitable library research. He was pleasurably surprised to discover that his pupils were able to plan activities other than book work and to make suggestions that had not occurred to him.

The initial discussion centered upon the relative values of different metals, the pupils thinking at first in terms of the rare metals but quickly realizing that in terms of utility steel surpasses them all. The discussion quickly brought up some questions that were puzzling the pupils—"What is the difference between iron and steel?" "Why is steel better than aluminum for airplane engines?" and "Why doesn't stainless steel rust?"

The pupils seemed genuinely interested in these questions and Mr. Dewey suggested that they list all questions that they would like answered.

Some of the pupils wanted to attack these problems immediately but the majority proposed a more systematic and comprehensive approach. As a result, problems of a more general nature were set up. It was at this time that Mr. Dewey gave his first concrete help, chiefly in wording problems succinctly and in proposing aspects the pupils had not considered. Below are the problems that were finally established, as well as the preliminary problems:

Preliminary list of problems

1. What is the difference between iron and steel?
2. What is stainless steel?
3. How strong is steel?
4. Why can steel be picked up by a magnet?
5. Why is steel needed for airplane engines?
6. How does a steel-cutting torch work?
7. How are steel parts welded together?
8. What makes a knife blade lose its temper?
9. Why can't you paint over iron rust?

Final list of problems

1. How is iron produced from ore?
2. How is steel made?
3. What are the properties of steel?
4. How may the properties of steel be changed?
5. How is steel shaped into different objects?
6. What are the advantages of alloy steels?
7. How can iron rust be prevented?
8. What are some general and specific uses of steel?

The pupils worked by committees, one to each problem, with the intention of reporting back to the class on their findings. To make their reports interesting, they planned to use models, charts, collections, and other visual aids. For a total of five days the committees worked for the major part of the regular class periods on their problems and sometimes met outside school hours. Once each day, however, the class met as a whole to report

progress and difficulties. On the fourth day, Mr. Dewey led a discussion of the general principles of presentations. The pupils had many excellent ideas about the ways these could be made.

Presentations began the sixth day. One group had a model of a blast furnace and samples of ores, coke and limestone to illustrate its report. Another group had charts of open hearth furnaces and Bessemer converters. One group had obtained help from a physics teacher in setting up a demonstration of the reaction of steel to different stresses. Still another prepared an experiment on the tempering of steel, in which the others could participate.

Presentations took up the better part of three class periods. When the pupils were through, Mr. Dewey proposed that the presentation materials be made into an exhibit for display cases in the main foyer. Another period was used for preparation of the exhibit.

At the end of the unit, Mr. Dewey asked for an evaluation of the method used. All the pupils agreed that it was very effective. One girl exclaimed, "I never learned so much before in my life!" The culminating test of the unit bore out her claim.

Project units. The "project plan" was another of the experiments in individualized instruction that originated during the early years of the twentieth century. It was suggested first by the success of what were called "job assignments" in vocational agriculture, but came eventually to center more about academic problems than about such practical things as raising ten chickens and forty tomato plants.

Much of the good of the project plan can be incorporated into the science program. Science lends itself to the same types of practical projects as those used in vocational agriculture. A later chapter will deal with the nature and value of science projects. This section will deal with building units around the projects.

One type of project unit requires that pupils work alone on individual projects. The pupils have identical assignments such as: "Make a booklet of leaf prints." Or a list of possible activities may be presented so that pupils have a choice of the things to do. The following list was posted on a bulletin board to guide pupils in selecting a project for a seventh grade unit on common animals:

1. Catch a caterpillar and keep it alive in a cage, giving it proper food.
2. Start an ant colony.
3. Make an aquarium with some minnows in it.
4. Collect twenty insects, kill them and mount them properly.
5. Keep some earthworms in a box of soil.
6. Make a census of the birds living in your block.
7. Keep some water insects in an aquarium.

8. Make an aquarium for a pond snail.
9. Keep a land snail in a terrarium.
10. Keep grasshoppers in a cage.
11. Keep a tadpole in an aquarium.
12. Make a suitable habitat for a frog.
13. Keep a toad in a terrarium.

During the development of this unit pupils first made tentative choices of the projects they would work on and began reading about the animals to be studied. Each then planned the materials he would need. The better part of the next two periods was spent in setting up cages and making collecting equipment. The class then took a field trip to a nearby undeveloped park area where most of the animals were available. Parts of two following periods were spent in establishing the animals in the cages or aquariums and in reporting on activities. Although a new unit was started after the sixth day, the pupils kept their animals for about two weeks longer.

The teacher of the class discussed above used an interesting technique with his project units. While one section carried on a project unit, his other sections had a different type of unit. Through such rotation, he provided more working space for his pupils than he could do if all sections carried out projects at the same time.

Project work by small groups is popular with pupils who like to work together. As with previous examples, the projects may be assigned or choice may be permitted. Groups may be of uniform size or they may vary with the nature of the project.

Mr. Scarry used a project unit for an eighth grade study of astronomy. He suggested a number of possible projects and permitted pupils to suggest others. He did not specify the number of pupils who might work in a group but he controlled the maximum number of pupils who could work on any one project. Some of the projects chosen by the pupils were: charts of the solar system, a model of the moon, constellation viewers, and telescopes made from mailing tubes and lenses.

Mr. Scarry initiated the unit with a discussion of possible projects and ways to carry them out. This was followed by organization into groups and group planning meetings. Pupils were expected to collect needed materials within a certain time, until which time Mr. Scarry conducted an introductory study of astronomy. When everyone was ready, Mr. Scarry gave the class three periods for group work. At the end of the unit pupils displayed their projects to the others and discussions followed.

A teacher may also develop a unit in which the entire class works on one project. A teacher of earth science may suggest that the class set up a weather bureau making all the apparatus—hygrometers, rain

gauges, and so on. Or a class may prepare a map showing all the trees in a park. Assembly programs, radio programs and special exhibits make interesting project units for an entire class to work on.

In the Cherry Valley Central School, New York, pupils with good academic records were permitted to substitute earth science for the usual ninth grade general science course. The resulting class was made up of highly enthusiastic and capable pupils.

Early in the course the pupils became proficient in the use of contour maps. One year a pupil suggested that the class make a relief model of the area surrounding the community and thus a project unit was initiated.

The initial planning stages showed the need for a careful survey of the area. To obtain expert help with this phase, the class asked a civil engineer to explain the nature of a survey and the operation of the instruments used. Following his talk and demonstration, several boys made levels, plane tables, and other equipment in the school shop.

The engineer volunteered to help the class during the first day of the survey and supplemented the improvised equipment with his own instruments. The pupils demonstrated such a sense of responsibility that he left his instruments with them for the balance of the survey.

The survey required several periods even when supplemented by the out-of-school efforts of several of the pupils. But finally the data were complete and the pupils had a contour map from which the model could be constructed.

Before making the model the pupils had to investigate the media to be used. Committees were appointed to ask about and read about papier mâché and plaster of Paris. Experiments with these media were undertaken. Procedures for building up the contours were devised. Finally model making began.

Each class member was busy on some phase of the work. Some made molds, some mixed plaster. Some prepared trees from rubber sponges and houses from bits of wood. As work progressed the accuracy of the model was constantly checked against the data available.

Though five weeks were needed for the completion of the unit everyone agreed that the result was well worth the time. The model was attractive with its bright paints and its miniature trees, buildings and bridges. It was informative because of its wealth of detail. Parents brought the project to the attention of the town officials who provided for the display of the model in a public place. Everyone, it seemed, was happy with the results.

Suggested activities

1. Plan a teaching unit similar to the sample given on page 360. Make certain that you include activities that can be used to provide for each of the elements of a science unit described on page 352.
2. Plan a resource unit. Set up the first lesson plan to be used with this unit.
3. Assume that you have just completed a unit on "The Circulation of the Blood." What are some charts and models which your pupils can make to help them summarize and organize what they have learned?
4. You are about to study a unit on "Rocks" in a seventh grade general science class. List the motivation factors that you might be able to utilize to stimulate pupil interest in this unit.

Suggested readings

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Strickland, Ruth G., *How to Build a Unit of Work*, United States Office of Education, Bulletin 1946, Number 5, United States Government Printing Office (Federal Security Agency), Washington, 1946.

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BUILDING A SCIENCE PROGRAM

chapter 15

Building a completely new program is a major undertaking that requires an extensive knowledge of content, teaching procedures and young people. It is a task for the experienced teacher, or, better yet, for several experienced teachers.

The beginning teacher is advised to depend upon an already established program, one that has been designed by experienced teachers. He can find such a program in textbooks, state outlines, and local courses of study. He will be able to present an acceptable science course through the use of one of these ready-made programs.

A very little experience, however, reveals that a course of study prepared by others is not quite satisfactory. It does not anticipate exactly the needs and interests of the pupils. It does not fit exactly the teaching situation. It does not meet exactly the teacher's own interests and desires. Modification is called for. The sequence of the units can be reorganized. Some material can be deleted. New units may be added. All these improvements add to the value of the program.

There will come a time when a teacher feels capable of developing a completely new program, drawing freely upon other course outlines and upon his own experiences. The final product is custom built for the specific situations in which it is to be used.

BASING A SCIENCE PROGRAM UPON A TEXTBOOK

Several leaders in science education recommend strongly that a textbook be used as the basis for a science program. One author goes so

far as to claim that with so many excellent texts available, any time and energy spent on the construction of courses of study is "vain and utterly wasteful."[1] Such a strong stand may be debated, but there is no question that the textbook can be very useful to the young teacher who must initiate a science program.

The textbook as a course of study. A textbook is fundamentally a course of study, designed to stand alone without implementation. Its authors have spent much time determining the content that is most suitable for a wide variety of situations. They study traditional programs and they investigate unusual programs. They take into consideration such factors as the balance of the different areas, the maturity of the pupils for whom the program is designed, and the mandates of state education departments.

The authors also organize the content for effective presentation. Some authors arrange the content on a seasonal basis so that a teacher can make full use of field trips and seasonal materials. Other authors use a sequential development, building one section upon the learnings of previous sections. Though the decisions are arbitrary, they are based upon extensive experience with pupils in many different situations.

Textbooks contain a great many carefully selected photographs and diagrams that serve as valuable teaching aids. There are usually previews, pretests, vocabulary lists, summaries, review materials, suggestions for further study, and test items. All these features add greatly to the value of a textbook as a course of study for beginning teachers.

Limitations of the text as a course of study. Textbooks are designed to sell to a broad market. They must be usable anywhere in the country, in any type of school and in any type of teaching situation. A program suggested by a textbook is necessarily general. In consequence a textbook program truly fits no specific situation precisely. It cannot take advantage of resources unique to one community. It cannot anticipate local events. It can at best be only approximately seasonal in organization. Textbooks tend to contain much more material than can be treated adequately in the time available. This is because authors are under strong pressures to meet every interest and every demand.

Generally, a textbook program must be modified for maximum effectiveness in any single teaching situation. Superfluous material must be deleted. The remaining material must be rearranged to take advantage of local events and local conditions. New materials, based on local resources, must be added.

[1] Hoff, A. G., *Secondary School Science Teaching*, Blakiston, Philadelphia, 1947.

Present day textbooks are handicapped by a tradition established when textbooks were designed solely for use in the reading-recitation method teaching. They answer all important questions. They solve all basic problems. They detail all the steps of essential experiments and tell the pupils what should be observed and what conclusions should be drawn. Unless a teacher is careful to make use of problems and experiments not suggested by the text, pupils have little opportunity to speculate, to devise methods of attack, and to draw their own conclusions.

Selecting a basic text. The general characteristics of textbooks and some of the criteria for their selection have been discussed in a previous section. However, it is desirable to consider here the qualifications needed by a textbook that is to become the basis of a science program.

The most essential characteristic is flexibility. It should be possible to begin studying almost any section of the book at the beginning of the year. It should be possible to delete any section without hindering the understanding of following sections. It should be possible to rearrange the sequence of sections in almost any order.

The difficulty of the material must be considered in terms of the educational maturity of the pupils for whom the book is intended. Structural formulas of organic compounds are not well suited for the comprehension of eighth grade pupils. Vector analysis of alternating current machinery is too abstract for most physics pupils. Chemical equations mean little to pupils in sophomore biology.

If the material that seems too difficult makes up but a small fraction of the content of the text, and if the program is sufficiently flexible, a textbook may still be a useful program guide; the difficult material may be assigned to exceptional pupils only. But if the difficult material makes up a substantial part of the book, with pupil success dependent upon understanding it, the book may be a good reference but a poor course of study.

Adapting a textbook program to a local situation.

Mr. Wilbur accepted his first position in a school that had adopted a well-known textbook, the chapter headings of which are given in the left column of table 12. During his first year, Mr. Wilbur followed the textbook closely but by the end of the year recognized that a number of changes would improve his program for the coming year.

For one thing, Mr. Wilbur wished to use the good weather of autumn and spring for the study of plants and animals. This he could do by beginning his program with chapter eleven, "Adaptations for Survival" and closing with chapter twelve, "Conservation of Living Things."

Some of the material in chapter ten, "Communication in a Modern World," he discovered to be beyond the grasp of many of his pupils. He deleted this chapter as a unit, transferring the material on telegraphs and telephones to chapter three, "Electricity and Its Uses."

Original Organization *	*Modified Organization*
Introduction	11. Adaptations for Survival
1. Matter From Atom to Universe	8. Houses for Modern Living
2. Conservation of Natural Resources	9. (In part) The Automobile
3. Electricity and Its Uses	5. Building a Healthy Body
4. Light and Its Uses	3. Electricity and Its Uses
5. Building a Healthy Body	(New) The Processing of Meat
6. Conserving Our Health	4. Light and Its Uses
7. Machines for Modern Living	7. Machines for Modern Living
8. Houses for Modern Living	6. Conserving Our Health
9. Modern Methods of Transportation	2. and 12. Conserving Our Natural Resources
10. Communication in a Modern World	
11. Adaptations for Survival	
12. Conservation of Living Things	

TABLE 12. *Original table of contents from a ninth grade science textbook and the modifications of the program planned to fit the program to a specific situation.* (* From Smith, V. C., and Jones, W. E., *Using Modern Science*, Lippincott, Chicago, 1951.)

His pupils had shown an adequate knowledge of airplanes due to study in earlier grades so he deleted this material from chapter nine and expanded the remainder to make a unit on "Automobiles."

When school opened in the fall, a housing project was under construction near the school. To take advantage of the opportunities for field work, Mr. Wilbur shifted chapter eight, "Houses for Modern Living," into second place on his program.

Because many of the parents of his pupils worked in a large meat packing plant, Mr. Wilbur planned a unit on the processing of meat. This he assigned to a time between two physical science units to provide better contrast.

Mr. Wilbur made a few other minor changes. He used the material of the introduction in his end-of-the-year review instead of at the beginning. He broke up chapter one, "Matter from Atom to Universe," and distributed the content among other units. He separated chapters five and six to provide more variety and contrast. He combined chapters two and twelve. His final program is shown in the righthand column in table 12.

Thus Mr. Wilbur tailored his program to fit his special needs. He did so believing that his new program would be far more interesting and profitable for his pupils. But despite the many changes he actually departed little from the content of the original plan.

Mr. Wilbur's new outline illustrates four types of modifications that may be made in an elastic textbook program: (1) The content was given a general reorganization; (2) some material was deleted; (3) certain sections were broken up and the material reassigned to other sections; and (4) new material was added.

Reorganization on a seasonal basis is the most obvious modification that one may make. Mr. Wilbur, if he had thought of it, could have anticipated the need for this type of change at the very beginning. An organization that permits the use of seasonal materials is of special importance in general science and biology; it also has value in any courses that use field work.

Reorganization on a psychological basis is less obvious but equally important. Certainly, to produce favorable first impressions, a science program should begin with material that will be interesting to the greatest number of pupils. Generally the most satisfactory opening units are based upon extensive field work, individual experimentation, and project work.

In general science especially, with its great range of pupil interests and abilities, it is advisable to provide variety in the program by *alternating units of entirely different characteristics.* Pupils who are not stimulated by one type of unit have greater possibilities for being challenged by the next. In the elective sciences the need for variety and contrast may be less important but should not be ignored.

Mr. Wilbur had two criteria for *deleting some of the content* of the textbook program. Certain items he found too difficult for the majority of his pupils. Other items he found repetitious of work they had done before. Had his textbook contained too much material to be covered adaquately, he would have found it necessary to weigh the value of the different sections in order to decide which to retain.

Mr. Wilbur broke up two chapters which he felt had little appeal as presented in the text. The material in these chapters he assigned to other chapters. This practice necessitates a certain amount of cross-referencing and sometimes calls for special outlines to help pupils keep their thoughts organized.

When *new material is added to the program,* it may be organized in one or more complete units as Mr. Wilbur chose to do. Or it may be added to already existing units in the form of subordinate sections. Usually the new material overlaps some of the material included in the

text. When it does, pupils may use the books as a reference during the study of the new material.

UTILIZING ESTABLISHED COURSES OF STUDY

Among the resources available for the planning of science programs are courses of study prepared by state and local agencies. Such courses of study generally represent several years of work by experts in science teaching fields. The courses of study have often been tried out on an experimental basis, and they have usually been submitted to expert teachers for review and criticism.

According to general practice, courses of study are suggestive only. Occasionally a school system demands that a teacher base his program on a certain course of study, but usually he has full freedom to reorganize the material to fit his special needs.

Strengths and limitations of established courses of study. Courses of study, like textbooks, define the content that has been found satisfactory for a good program. They present a pattern of organization that has been found effective. They suggest teaching procedures—experiments, demonstrations, field work, and projects. They give lists of books, films, and slides suitable for supplementing the program.

Courses of study are designed for statewide or community use and are somewhat more specific than textbooks can be. Nevertheless, they are not so well adapted to the needs of an individual teacher as is a program he himself has developed. Courses of study are not so self-contained as are textbooks. A teacher must have a larger file of supplementary materials to use them effectively. For this reason, beginning teachers are usually attracted to textbooks.

Experienced teachers often prefer to base their programs on state or local courses of study. They find that textbooks are not well adapted for the problem-solving method of teaching because all major questions are answered and all basic problems are solved. These teachers want the pupils to devise their own methods of attack on problems, make their own observations, and draw their own conclusions.

Modifying a state course of study for local use. Courses of study may be modified in much the same way as are textbook programs. The organization may be altered, material may be deleted, units may be broken up and distributed among other units, and new material may be added either in the form of new units or to supplement existing units. The teacher has somewhat greater flexibility in breaking up units and reassigning material than when using a text because textbook units tend to be highly integrated.

The major headings of a state course of study in physics are given below.

I. The Relationship of Physics to Life
II. Man's Control of Liquids and Gases
III. The Nature of Molecular Forces
IV. The Relationship of Forces and Motion
V. Machines Do Work
VI. The Nature of Heat
VII. The Nature of Sound
VIII. The Nature of Light
IX. The Nature of Magnetism
X. The Nature of Static Electricity
XI. Man Uses Electricity in Motion
XII. The Nature of Electro-magnetic Induction
XIII. The Nature and Value of Radiations and Electronics [2]

Though the organization follows the pattern found in so many textbooks and syllabuses, there is actually no reason save tradition why the organization cannot be radically altered if a teacher sees sufficient advantage in doing so.

After some eight years of teaching, Mr. Tanner found himself dissatisfied with his physics program. Too few pupils were electing the course. Too many were dropping the course in discouragement.

Unquestionably his pupils were being given an unhappy introduction to the course. "Why must a physics course begin with mechanics and the metric system?" Mr. Tanner asked himself. "Why not begin with some area that has immediate appeal to the pupils and that uses a minimum of mathematics? Why not introduce the metric system gradually and delay difficult conversions until after pupils have developed facility with both systems of measurements?"

Mr. Tanner chose the study of light for an introductory unit. He kept interest high through the study of cameras, telescopes and photography He encouraged extensive project work—pinhole cameras, periscopes, picture projectors. He used problems that depended upon simple mathematics for solution and he introduced only millimeters and centimeters into the system of measurements.

His second unit centered about the study of electricity. The introduction was generally non-mathematical, with several field trips, numerous experiments, and extensive project work. Towards the end of the unit mathematics was used more extensively.

The third unit, "Electronics," was an extension of the second unit. His pupils encountered no difficulties with the material presented. Project

[2] Science for Oregon Schools, Part II, *High School Science*, Anderson, Robert E., ed., Oregon State Department of Education, 1949.

has so many needs. There is so much material from which to choose, all of it worthwhile. There are so many variables to be considered. Program makers need some clearly defined principles to guide them.

Criteria for the selection of course content. A study of opinion conducted by the National Association for Research in Science Teaching produced the following criteria for the selection of course content.

Course content in science should:

1. Be in harmony with accepted objectives set up for the pupils.
2. Lead to the inculcation of appropriate scientific attitudes and understanding of the methods of science.
3. Encourage the belief in, and practice of, desirable social ideals involving science.
4. Be of direct use to pupils in their daily living.
5. Be appropriate for the ability level of the pupils.
6. Aid pupils in the interpretation of local and world environment.
7. Be in harmony with the needs and interests of the pupils.[3]

These criteria are necessarily general and capable of broad interpretation. They should not be applied singly because almost any item of subject matter is certain to fit one of them. They should be applied as a whole to every possible item of content to insure a worthwhile and satisfactory program.

It is well to develop more specific criteria to govern the selection of content for courses of study in special fields. These will state the same thoughts but in more direct terms. The list below gives the criteria used by the New York State Regents Biology Committee in preparing the 1958 syllabus in biology:

1. Biology must derive its freshness and its unique approach from the firsthand study of living plants and animals.
2. Coming when it does in the lives of young people, biology must be related to the special needs of adolescents.
3. Biology should derive its language from the requirements of the concepts which are developed. Terminology, thus, should not become an end in itself but rather a tool to understanding.
4. Biology content needs to change as the science of biology changes.
5. The method of learning is as important as the content in achieving the objectives of biology teaching.
6. The climate of the biology classroom should be such that it interests all students and at the same time challenges, stimulates and encourages students with special science talent.[4]

[3] *Science Education in American Schools*, Part I, Forty-sixth Yearbook of the National Society for the Study of Education, The University of Chicago Press, Chicago, Ill., 1947.

[4] *Biology, Topics and Understandings for a Course of Study in the Science of Living Things*, New York State Education Department, Albany, 1958.

Mandated content. A program maker should acquaint himself with the laws and decrees that govern the content of science courses for his particular community. Many states have laws that require instruction in the effects of alcohol, tobacco, and narcotics on the human body. There are sometimes state and local decrees mandating the teaching of health, safety or conservation.

Mandated material can usually be woven into the program without being isolated in specific units. The effects of tobacco may be studied in a unit on the nervous system, in a unit on disease, or in a unit on physical fitness, or in all three units. Properly treated, mandated material can be used to attain the general objectives of science education in the same fashion as other materials.

Content of high intrinsic worth. Some items of content are so obviously important to young people that no one questions their place in the science program. Most of these items fall into the areas of health, safety, and conservation. Two teachers who disagree sharply about the relative merits of the study of spiral nebulae or meadow mice find no quarrel about the merits of studying fire prevention and good diet.

Content material of value should be given high priority in all program making. General science teachers and biology teachers have always recognized their responsibilities to include material on health, safety, and conservation. Physics and chemistry teachers, with their attention focussed on abstract principles and mathematical treatment, have been slower to recognize their obligations. Yet a physics course is an excellent means for studying the behavior of automobiles under various driving conditions. And a chemistry course has much to offer to the understanding of nutrition.

Complete units can be built around materials from the areas of health, safety, and conservation. Such units are easy to develop because there is a wealth of possible experiments, field studies and individual projects. Material on these topics may also be woven into other units. Thus a physics unit on stability and balance may include a study of safe walking. An earth science unit on storms may include a section on safety practices during thunderstorms. Such inclusions give additional significance to the units involved.

Selecting content in terms of local resources. There are some superb teaching situations around most schools. For one school it may be a pond. For another it may be a bakery. For still another it may be a museum. These resources should not be neglected. It is always wise to begin the task of program construction by making an inventory of the resources available for science teaching. Such an inventory needs to be brought up to date periodically.

Bureau of the State Education Department commissioned research workers to develop a file of teaching activities suitable for the junior high school grades. More than a thousand suggestions were collected, tested, refined and classified under suitable headings.

A committee of experienced teachers then made up an outline into which the suggestions for activities could be fitted. Consultants continued to refine the suggestions and to collect additional suggestions to round out the program. Finally the consultants determined from the activity suggestions the learnings that pupils might gain by carrying out the suggestions. The completed program has been published in the form of three handbooks of suggestions for the three years of the junior high school, together with a syllabus that outlines the program and tells how to use the handbooks.[5]

This approach to the selection of content has much to recommend it. All material included is known in advance to be teachable through first-hand experience situations. This type of program benefits all pupils, whether they are retarded readers or academically gifted. The program permits maximum flexibility.

Selecting content to provide a balanced program. A well-balanced science program brings together elements from the many areas of science and gives them equivalent emphasis. The need for a balanced program gave rise to general science in the early part of the century. The specialized sciences have always tended to be too narrow; each would be improved by the inclusion of material from the transition sciences, biophysics, biochemistry, geophysics, geochemistry and physical chemistry. Balance improves the exploratory function of the science program. Pupils become acquainted with more areas of science and have increased opportunities to discover their special interests and abilities.

Provision for balance adds much to the appeal of a science course. Each pupil is more certain of finding areas in which he can gain satisfaction. In the narrowly based course his special interests may not be met and he may develop a strong dislike for his work. Perhaps the cause for the unpopularity of physics among girls is the narrowness of its range, which confines it to materials of little interest to girls.

While providing for balance, the program maker should beware of including too much material. The well-rounded program need not try to cover all that is known about science. Instead it samples a bit here and a bit there from widely differing fields.

Balance is improved by developing units that cut across traditional

[5] *Science 7-8-9*, New York State Department of Education, Albany, 1956. *The General Science Handbook*, Part I, 1951; Part II, 1952; Part III, 1956.

boundary lines into two or more fields of science. A unit on the analysis of human motion does much to broaden the physics program. The study of soils fits excellently into the chemistry program. Earth science should deal with the relation of plant societies to soil and topography.

Consideration for pupils' backgrounds. A program designed for pupils with rich experience backgrounds may be much different from a program designed for pupils who have seen and done little. Pupils who have had many direct experiences with soil erosion can grasp quickly the significance of much that they read in books and see in films. But pupils whose lives have been spent in crowded cities need basic experiences with the effects of rainfall, cultivation, slope and vegetation before words and pictures take on real meaning.

The experience backgrounds of pupils cannot be taken for granted as they once were. Only a few generations ago young people encountered at every turn domestic animals, simple tools, elementary manufacturing processes, fires both useful and harmful, and countless other simple applications of science. When these young people entered the schoolroom they possessed a rich background of experience upon which to build. Today this condition no longer exists. The program maker should realize that the need for firsthand experiences is far more important today than in the past. He should base more of his program upon experiments, field work and demonstrations. He should use content that depends solely upon words and pictures with care lest he encourage pupils to talk glibly of things about which they know little.

Content must also be chosen with more attention to opportunities for individualized work than was once considered important. Boys and girls vary greatly in their backgrounds; some have traveled widely, lived in favorable conditions and had many exciting experiences; others have lived limited lives with their experiences confined chiefly to television and movies.

The dangers of superficiality. Superficiality is opposed to all that is good in a science program. Hasty inadequate teaching leaves pupils confused, dissatisfied, and uncertain about their own science aptitudes. They have little time to explore their special interests. They have little opportunity to feel the satisfaction of success.

When a program contains too much material, a teacher is forced to deal with broad generalizations. He has little or no time for teaching through experiments and field work. His demonstrations must be used to illustrate broader principles than they are justified to do. He must force pupils to accept statements which they do not understand. He cannot prepare them to deal with exceptions and deviations.

Superficiality tends to discourage pupils. As the teacher hurries from

topic to topic the pupil who stops to think about the implications of a statement is left behind. If he is to keep up with the group, a pupil must accept statements with the hope that their meaning will become clear later. There are a few pupils who do try to think through unclear statements and who go to the teacher for help in understanding. But many pupils shrug their shoulders, assume that they lack scientific aptitude, and hope that they can pass their courses by being no worse than the majority of their fellows.

Superficiality hinders progress towards the general goals of science education. The development of a scientific attitude requires thoroughness of treatment with sufficient time for careful consideration of each point. Only thus are pupils able to form the habit of questioning, of looking at both sides of an issue, and of retesting doubtful conclusions. Superficiality forces a pupil to accept the authority of text and teacher, and fosters the habit of blind acceptance.

The Forty-sixth Yearbook of the National Society for the Study of Education gives an extensive analysis of the scientific method and provides the following illustration of the type of problem that may be utilized:

A class in general science was showing only average interest in the study of bacteria cultures as related to a problem in health until a pupil raised the question of the dangers of kissing. The next day a pupil brought in pictures of cultures taken from the lips of college men and women. The class interest was high at once. They wanted to try the experiments. Several members of the class gave up a movie on Saturday to come to school and prepare more culture plates for the experiment. The experiments were tried and the days while the plates were incubating were "red letter" days as far as pupil interest was concerned. When problems become real to young people their interest in the solution will always follow.[6]

The solution of a problem such as this one requires time. Certainly the major parts of two periods must have been spent in planning and setting up the experiment. Portions of other periods must have been given to making observations and discussing results. A science program that attempts to cover a vast amount of material could not possibly permit a class to spend four or five days on so minor a topic.

And yet the activities described above have important outcomes. The pupils have gained a deeper insight into the scientific method of problem solving. Their habits of independent thinking have been strengthened. Their interest in science has been enlarged. And their

[6] *Science Education in American Schools*, Part I, Forty-sixth Yearbook of the National Society for the Study of Education, The University of Chicago Press, Chicago, Ill., 1947.

learnings, which are based on firsthand experiences, have provided a sound basis for understanding the related material encountered in books, movies and television. Such values certainly justify the time needed to produce them.

Two radically different factors act together in encouraging superficiality in the science program. Tradition is one factor; this holds material in the curriculum after the material has lost its usefulness. Modernization is the other factor; it adds new material to the program without balancing its value against materials already present.

Tradition has a greater effect than many people realize. During a revision of a state course of study in general science, the curriculum bureau received a surprising number of letters protesting the deletion of lift pumps and other devices that have practically disappeared from the American scene. Teachers are apt to forget that the things in which they were interested as adolescents may have little significance to young people today. When choosing content for a program, teachers should evaluate each item in terms of its present day significance and show no reluctance in deleting telegraphs, grindstones and hydraulic elevators.

Over-zealousness in including modern developments in science can also be detrimental. Much that is read about in the newspapers is not suitable for secondary school science programs. Such timely topics should be judged by the criterion that states that content should be appropriate for the ability level of the pupils.

Many pressures are brought upon teachers to include material of special interest into the curriculum. Some of the pressures come from groups deliberately organized to influence the curriculum. Other pressures, often more subtle, come from other teachers, parents, the press, industries, and even the pupils themselves. Usually these influences are well intentioned and are actuated with a sincere belief in the importance of the recommendations. No program maker need quarrel with the motives even when he may not agree with the proposals. Nonetheless he should evaluate them critically, looking for those that might be profitably included, for those that are obviously impractical, and weighing the remainder against those that already have a place in the curriculum.

ORGANIZING THE CONTENT OF A NEW PROGRAM

A number of plans for the organization of science content have been developed during the past half century. The types that have persisted are those that permit maximum flexibility of treatment. Intricate and highly formal outlines do not survive.

The following pages will describe some of the more common plans for organizing content and discuss their strengths and limitations. None is recommended as superior to the others. Accomplished teachers have had success with each. It is probable that there is no one superior plan, teaching being such an individual matter.

The most important characteristic of any pattern of organization is flexibility. It is impossible to foretell the direction of pupil interests and the nature of the situations that will be encountered in the classroom. A teacher should be in a position to take maximum advantage of whatever arises—a newspaper clipping, an unusual bird nest, a burned-over field, or a water shortage. He should be able to adjust his program to the needs of the moment.

It must be realized that flexibility is chiefly a state of mind on the part of the teacher. Some teachers, even given the most free and flexible program possible, will follow it blindly step by step. Other teachers will find ways to adapt any program to the needs of their pupils no matter how rigid it seems to be at first glimpse.

However, some types of programs are easier to use effectively than others because of the type of organization. Programs composed of independent sections are most flexible; their component parts may be taken up in any order as seems best for the occasion. Programs that are strictly sequential, with the outcomes of one section completely dependent upon what has gone before, cannot be altered conveniently if at all.

Flexibility is promoted by the use of short, discrete, and independent units. Such units may be presented in whatever order seems most effective at the time. Full advantage can be taken of seasonal materials. Should an unexpected event occur, a relevant unit may be taken up immediately while interest is high. Should new material seem valuable, it may be organized as a unit and substituted for a unit already in the program.

A "minimum core" program promotes flexibility and guarantees freedom to follow up special interests. The content of the "minimum core" is strictly limited to require not more than three-quarters of the time allotted to the program; commonly the minimum core may be even smaller. The remaining time is reserved to be used as seems most beneficial. New units may be introduced or parts of the minimum core may be expanded.

Flexibility can be made a feature of the general science program with relative ease. The topics of general science are not closely related and each is introduced at such an elementary level that few prerequisites are called for. The specialized sciences tend to be a bit less flexible than general science but, except in the case of chemistry, rigidity is due

more to tradition than to necessity. Even in chemistry the content has been organized according to several different though related patterns.

Organization by major topics. *From the early days of science teaching, it has been customary to break up the science program into blocks which center about specific areas of science.* Commonly the blocks are called "units" and are headed with such titles as "Fire," "Water," "Insects," and "Nutrition." Below is the outline of a chemistry course organized in this fashion:

I. Early Chemistry
II. Pioneers of Chemistry
III. Physical and Chemical Changes; *Elements, Compounds*, Mixtures
IV. Units of Measurement; *Temperature and Heat*
V. Oxygen
VI. Atoms and Symbols
VII. Hydrogen
VIII. Valence, Formulas, Equations
IX. Water
X. Chemical Calculations
XI. *Carbon and Carbon Dioxide*
XII. Carbon Monoxide and Fuels
XIII. Molecular Motions and Their Effects
XIV. Combination by Weight and Volume
XV. Ionization in Solution
XVI. Acids, Bases, and Salts
XVII. Sulfur, Hydrogen Sulfide *and Sulfides*
XVIII. Oxides and Oxygen Acids of Sulfur
XIX. *Periodic Classification and* Atomic Structure
XX. Chlorine and Hydrogen Chloride
XXI. The Halogen Family
XXII. Nitrogen and the Atmosphere
XXIII. *Compounds of Nitrogen*
XXIV. Sodium and Its Compounds
XXV. Typical Metals and Their Compounds
XXVI. Organic Chemistry [7]

Contrary to some of its critics, this form of organization can be used successfully. The material in each block lends itself well to the problem-solving approach, and provides for the development of important knowledge and skills.

Unfortunately it also lends itself to misuse, particularly by teachers who accept consciously or unconsciously the doctrine of mental discipline. It is very easy with this type of organization to proceed rapidly to the study of abstractions, ignoring or minimizing commonplace applications, and plumbing depths that are not justified by the *time and* facilities available.

The following outline for an eighth grade *unit on water, developed* by a student teacher, *illustrates the ridiculous extremes to which this* type of organization lends itself:

[7] Hogg, John C. and Bickel, Charles L., *Elementary General Chemistry*, D. Van Nostrand Co., Inc., Princeton, N. J., 1945.

Water

1. Physical properties: appearance; density; change of state.
2. Water Pressure: relation to depth; direction; transmission.
3. Buoyancy: cause; laws of floating and submerged bodies; effects of density.
4. Water in motion: causes; nature of energy; energy-pressure relations.
5. Water as a solvent: solubility and insolubility; factors affecting solubility; saturation and supersaturation; crystallization.
6. Composition of water: chemical formula; production of water; electrolysis of water.

This student teacher was so concerned with treating the subject of water thoroughly that he forgot the nature of his pupils, the time available to him, and the nature of the learning process.

A second disadvantage of the use of broad topic headings becomes obvious when the units are fitted into the complete secondary school science program. The above unit on water was developed for the eighth grade. Any further study of water in subsequent years would tend to be repetitious. And yet that student teacher would not claim that the study of water should end with the eighth grade.

Topic organization can be more successful if the content is limited by the use of more specific headings. The contents of a unit on water, from a general science text written in the early days of that subject, is shown below:

UNIT II. Water and how we use it
Project V. Water in our homes
Project VI. Water in the air
Project VII. Water and the soil [8]

Note that the headings of each "project" tend to limit the contents to reasonable confines. Note also that in terms of the over-all secondary school science program, additional study of water is possible without repetition.

The use of major topic organization seems to be regaining popularity today after a number of years of disfavor. The New York State General Science Syllabus, described on page 391 uses topic organization. The table of contents of a recent ninth grade general science text, given below, is also based on major topics:

Unit 1. Man—As Scientist
Unit 2. Lengthening Man's Life
Unit 3. Exploring the Earth and Space
Unit 4. Understanding the Earth's Weather

[8] From Van Buskirk, E. F., and Smith, E. L., *The Science of Everyday Life*, Houghton-Mifflin, Boston, 1919.

Unit 5. Investigating the Earth's Storehouse
Unit 6. Improving the World's Food Supply
Unit 7. *Doing the World's Work*
Unit 8. Improving the Exchange of Ideas [9]

The "major problem" pattern of organization. The Forty-sixth Yearbook Committee of the National Society for the Study of Education makes the following recommendation:

1. Content should be organized into large areas or units, each of which represents some major problem of living, area of human experience, or aspect of environment.
2. *The content of any single area or unit should be broken down into* smaller learning problems which have interest, significance, or usefulness to the learner.

This type of organization was designed to give young people a broad view of the purpose of their study. It was developed to replace the abuses of the topic method of organization. The school of thought represented by it is the same as that responsible for the Thirty-first Yearbook.

Many textbooks and courses of study have been organized on the major-problem basis. The table of contents of a seventh grade general science book written in the 1930's is given on pages 400-401. This table of contents illustrates both the strengths and weakness of the pattern.

Foremost among the strengths is the informal, natural approach to the study of science. The material treated lies within the experience of the pupils. Few abstractions are introduced. The breakdown into sub-problems is worthy of study. Pupils think in terms of small problems. They are apt to be discouraged by problems that require several weeks for solution.

There have been two unfortunate abuses of the major-problem pattern of organization. The major problems chosen often represent areas that should be treated through several years of the secondary school program. Unit eleven, for instance, deals with a subject that merits attention throughout the secondary science program. Any further work, however, would tend to be repetitious. Unit Seven, How Do Magnets Work? is a much more satisfactory choice of unit heading.

A second unfortunate outcome of the major-problem pattern of organization is the assumption by teachers that because the program headings are stated as questions the problem method of teaching *is* being used. Nothing may be farther from the truth.

[9] From Brandwein, P. F., Beck, A. D., Hollingsworth, L. G., and Burgress, A. E., *You and Science: Science for Better Living*, Harcourt, Brace, New York, 1955.

TABLE OF CONTENTS OF A SEVENTH GRADE GENERAL SCIENCE TEXT *

Unit 1: How Do Scientists Make Discoveries?

Problem 1: How do scientists find problems?
Problem 2: How do scientists solve problems?
Problem 3: How have scientific instruments helped scientists solve problems?

Unit 2: What Kind of World Do You Live In?

Problem 1: What conditions surround us on earth?
Problem 2: What materials do we find in our world?
Problem 3: What living neighbors do we have?
Problem 4: What natural forces do we use?
Problem 5: What kind of body does man have?

Unit 3: What is a Material?

Problem 1: How are all materials alike?
Problem 2: What are solids, liquids and gases?
Problem 3: What is a solution?
Problem 4: How are materials put together?

Unit 4: How Do Heating and Cooling Change Materials?

Problem 1: How do heating and cooling change the size of materials?
Problem 2: What effect does heating have upon the state of matter?
Problem 3: What happens to materials when they are cooled?
Problem 4: How can we explain how heat affects matter?

Unit 5: How Can One Kind of Substance Change into Another Kind?

Problem 1: What are materials made of?
Problem 2: How can we recognize a chemical change?
Problem 3: How can we control chemical changes?
Problem 4: What are two kinds of simple chemical changes?

Unit 6: How Do We Use and Control Fire?

Problem 1: What happens when things burn?
Problem 2: How do we make fire?
Problem 3: How do we regulate fire?
Problem 4: How do we prevent and extinguish accidental fires?

Unit 7: How Do Magnets Work?

Problem 1: What will a magnet do?
Problem 2: How can we make magnets?
Problem 3: Why do magnetic compasses tell direction?
Problem 4: How is magnetism explained?

Unit 8: How are Plants and Animals Alike?

Problem 1: How are plants and animals alike in what they do?
Problem 2: What chemical substances are living things made of?
Problem 3: How are plants like animals in the way they are put together?

Unit 9: How Do Plants and Animals Get Food?

Problem 1: How do animals get food?
Problem 2: How do green plants get food?
Problem 3: How do plants that are not green get food?
Problem 4: How do plants make food?

Unit 10: Why Do We Eat Different Kinds of Food?

Problem 1: Why do our bodies need food?
Problem 2: What kinds of foods meet the different needs of the body?
Problem 3: How can we select our foods wisely?

Unit 11: How Do Plants and Animals Live Together?

Problem 1: How do plants and animals depend upon each other?
Problem 2: How do social animals help each other?
Problem 3: How is the balance of life maintained?

* An illustration of a program organized by major problems and sub-problems. (From *Science Problems, Book One*, by W. L. Beauchamp, J. C. Mayfield, and J. Y. West, Scott, Foresman and Co., Chicago, 1938.)

The problem method of teaching makes use of problems that are recognized by the pupils themselves. The teacher may set the stage for a problem or may help pupils verbalize a problem, but pupils must accept a problem as their own for it to be effective.

Looking again at the above contents, we see that many of the questions do not by themselves represent pupil problems. The question

"How is the balance of life maintained?" is not of the type that challenges seventh grade boys and girls. The question "How can we make magnets?" is one that is much more readily accepted, but there are too few of these. For all practical purposes most of the headings might as well be stated in declarative form—"The Effect of Heating and Cooling Materials" and "How We Regulate Fire."

The program maker may avoid some of the weaknesses that have been discussed by using the major problems as themes that run throughout the twelve years of schooling. His unit headings then become sub-problems. These sub-problems should be chosen so they do not duplicate each other within the secondary school program.

Organization on the basis of field experiences. Nature study courses taught during the early part of this century were sometimes based completely upon field work. Each new trip provided the content for the follow-up classroom work. The program was dictated by the trips that were possible and by the material that was available at the time of the trips. Far from being haphazard, these courses were often highly effective. In the hands of a teacher who knew his local environment well the program could be orderly and well-balanced.

Earth science, biology and ecology courses lend themselves to this type of organization. Experimentation may reveal that other sciences might be centered about field experiences equally well.

Organization about laboratory experiences.

> "My physics course is just one long laboratory period," is the way Mr. Sweetwater describes his program. "The pupils begin with experiments the first day and continue with them until the end of the year."

Mr. Sweetwater's program is built around laboratory work. Each of the nearly two hundred required experiments presents a problem for the pupils to solve. Some problems are simple, some are complex. Pupils are expected to master each in turn.

His program is reminiscent of some of the individualized programs of the 1920's. Pupils work at their own rate. Each individual is expected to set up the apparatus for an experiment, perform the proper manipulations himself, and collect his own data. He must satisfy Mr. Sweetwater in a personal conference that he has mastered the problem. Only then may he undertake the next problem.

A similarly organized course in ninth grade electricity is described on page 116. The individual pupils are presented with a series of tasks, each of which must be mastered in turn. It is important to note that the tasks involve actual materials and are not basically bookish in nature.

SETTING UP A SIX-YEAR SCIENCE PROGRAM

A school may offer six years of science courses without offering a six-year science program. A program, by the very meaning of the word, has unity of purpose, unity of approach, and unity of procedure.

In the six-year science program a pupil is provided with a carefully developed sequence of experiences. He does not repeat experiences, save as he wishes, but he reviews his understandings through encountering situations that are similar to situations he has encountered before. His understandings are continually deepened and broadened as he finds himself in increasingly complex situations.

The six-year program is possible only through the cooperation of all teachers concerned. These teachers must agree as to the purpose of their teaching and the methods they will use in attaining their goals. They must work closely together throughout the entire planning process.

Establishing the experience backgrounds of the pupils. An inventory of the experiences that pupils have had before entering the secondary school is useful in planning the secondary school science program. The inventory indicates experiences that need not be repeated. It also indicates experiences that may be referred to during classroom discussions.

It is easier to inventory the experiences of pupils than to inventory their learnings. The former may be obtained by investigating the activities used in the elementary school science program. The latter must be obtained from verbal tests and may give information of little value to the program maker.

Secondary school teachers who participate in the planning of the elementary school program gain a better understanding of that program and what may be expected of pupils who complete it.

The Fayetteville-Manlius Central School system is engaged in planning a twelve-year science program. Committees of elementary teachers, assisted by secondary school science teachers as consultants, are preparing the elementary portion of the program. After this portion is complete, the secondary school teachers will build their program upon it.

Establishing sequence in the program. Planning on the basis of experiences is as helpful for building a six-year program as for building a one-year program. Setting up sequences of experiences helps reduce omissions and unnecessary repetitions, and insures steady growth through the use of increasingly complex situations.

Procedures for collecting and organizing suggestions for pupil ac-

tivities into a program are described on page 391. For the six-year program the suggestions must be more numerous and should have a greater range of complexity.

To provide a framework on which the activity suggestions may be organized it is helpful to choose a number of science areas that are to be developed concurrently through the program. Several areas that may be used are listed below:

1.	2.	3.
Animal anatomy and physiology	Nature of the earth	Mechanical energy
Plant anatomy and physiology	Rocks, minerals and soils	Machines
Nature of the human body	Crustal movements	Mechanics of gases
Maintaining health	Erosional processes	Mechanics of liquids
Practicing safety	Earth history	Radiant energy
Animal reproduction	The atmosphere	Heat
Plant reproduction	Season and climate	Sound
Inheritance	Weather	Electricity
Evolution	Time, place and direction	Magnetism
Interdependence of living things	Astronomy	Nature of matter
Economic biology		Physical changes
Conservation of living things		Chemical changes

Sets of experiences in the area of electricity and magnetism may be allocated to the several courses that make up a secondary school science program as shown below:

Course	*Sets of experiences*
Seventh grade science	Simple circuits, switches and fuses
Eighth grade science	Magnets and electromagnets
Ninth grade science	Production of electrical energy
Biology	Reactions of organisms to electricity
Physical science	Electricity in homes and automobiles
Earth science	Earth's magnetic field and atmospheric electricity
Chemistry	Electrochemistry
Physics	Electrical and magnetic theory applied.

In two courses, biology and earth science, there are not enough suitable activities to warrant full units but the activities may be made part of other units without changing the fact that a sequence has been preserved. In the other courses there are sufficient numbers of possible experiences to warrant full units.

This sequence on electricity and magentism shows a progressive development in complexity from the seventh grade onward to the

terminal course. There are no repetitions of experiences and little chance for serious omissions, and the work of one course builds directly on the work of preceding courses.

The New York General Science Course of 1956, already described on page 391, illustrates how a sequence is established by the use of content areas. Ten areas of science, shown in Table 13, were selected to be developed through the junior high school years. Sets of activities were allocated to each area for each grade and units were developed about these activities.

Area	*Grade seven*	*Grade eight*	*Grade nine*
Nature of Living Things	The Living Things Around Us	Plant and Animal Habitats	Tiny Plants and Animals
The Human Body	Taking Care of Ourselves	Foods and How We Use Them	The Body in Action
Electricity and Magnetism	Electric Circuits	Magnets at Work	Electricity at Work
Machines	Overcoming Gravity and Friction	How Airplanes Fly	Travelling on Wheels
Chemical Changes	Fire	Working Safely with Chemicals	Chemical Changes in Everyday Life
Radiant Energy	Making Use of Light	Sunlight and Green Plants	Living with the Atom
The Atmosphere	Air at Work	Living in an Ocean of Air	Weather and Climate
Things in the Sky	The Change of Seasons	Neighbors of the Earth	Keeping Time and Locating Places
Things of the Earth	Natural and Artificial Rocks	Changes in the Earth's Surface	Water and Its Uses
How Living Things Maintain Themselves	Flowers and Seeds	Life Cycles of Animals	Conserving Forests and Wild Life

TABLE 13. *Organization of the New York State General Science Syllabus, showing the sequence of units from grade to grade.*

It will be noticed that each unit in a sequence is somewhat more complex than the unit immediately preceding it and that in general a

unit builds upon previous units of a sequence. Experiences of one unit are not repeated in the next but there are opportunities for review of understandings as related situations are introduced.

"Double and triple track" programs. A single science program cannot take advantage of all the range of interests and aptitudes in a school. Even with "ability grouping" and with all possible provision for individual differences, a single general science program is still a single program designed neither for the academically brilliant or the academically retarded. The senior high school program as usually offered is made up only of courses designed for pupils with high scientific aptitudes. Were the senior high school program redesigned for the majority of the pupils, the extremes would still be neglected.

One solution to the problem as attempted by some school systems is the development of two programs, each with its own sequence of courses. One program is designed for pupils with high scientific aptitudes. It anticipates that these pupils will continue their study of science in colleges and universities. The other program is designed for the great majority of pupils and is looked upon as terminal. Some authorities recommend the development of still a third program for the academically retarded, not a course designed for the feeble-minded but one that puts almost complete emphasis upon firsthand experiences and project work.

There are serious administrative difficulties in adopting "multiple track" programs. Small schools do not have the staff or facilities to handle two programs. In any school the problem of scheduling classes can be enormous. However, "multiple track" programs may be an answer to the problem of giving more pupils science training of a type suited for them. The New York State Education Department is encouraging the use of "double track" programs by preparing special syllabuses to meet the needs of local program makers.

The chart below gives two possible sequences of courses based upon the New York State syllabuses.

Grade	*Non-academic program*	*Academic program*
Seven	General science	General science
Eight	General science	General science
Nine	General science	Earth science
Ten	Biological science	General biology
Eleven	Physical science	General chemistry
Twelve	Earth science	General physics

For the high aptitude groups the usual three-year general science program is concentrated into two years. This is done, not by covering

the same amount of material in less time, but by judicious deletions. Material which the pupils undoubtedly mastered in the elementary school or through extra reading is omitted. Material dealing with earth science is deferred to the ninth grade earth science course. The proposed two-year general science program shown below is based upon the sequence given in Table 13, to permit pupils with superior science aptitudes to elect earth science in the ninth grade.

Grade seven	*Grade eight*
1. The living things around us	1. Plant and animal habitats
2. Taking care of ourselves *	2. The body in action
3. Electric circuits *	3. Electricity at work
4. Overcoming gravity and friction	4. Travelling on wheels
5. *Fire*	5. *Common chemical changes* *
6. Making use of light	6. Living with the atom
7. Living in an ocean of air *	7. How airplanes fly
8. Water and its uses	8. Conserving natural resources *
9. Flowers and seeds	9. Sunlight and green plants
10. Life cycles in animals	10. Tiny plants and animals

* Unit modified to include portions of other units in same sequence.

The four specialized sciences offered to the pupils with high scientific aptitudes are the traditional academic courses that have long been given in New York State schools.

The standard program, designed for the bulk of the pupils, begins with a three-year general science program. In the senior high school, pupils may elect a biology course that is less academic than the traditional course, a physical science course that fuses the less academic phases of general physics and general chemistry, and earth science, which has always been considered the least rigorous of the usual electives.

It is also possible to provide a third program based upon these syllabuses, a program for pupils who are seriously retarded readers but who are not unintelligent. The first two years of the general science program may be distributed over three years in order to provide more time for firsthand experiences and manipulative work. Of the remaining material the less academic and more practical phases may then be organized into an advanced general science elective course for the senior high school years. Such a program is shown on page 408.

Teachers who are planning double or triple track programs should be careful not to think *solely in terms of subject matter.* There are problems of experience background, interests, and social maturity that must be taken into consideration along with aptitude. Half a standard

GENERAL SCIENCE PROGRAM FOR PUPILS WITH LOW ACADEMIC ABILITY *

	Grade seven	*Grade eight*	*Grade nine*	*Advanced general science*
1.	Common plants around us	Common animals around us	Plant and animal habitats	Tiny plants and animals
2.	Looking our best	Taking care of ourselves	Foods and how we use them	The body in action
3.	Magnetism	Electric circuits	Electromagnetism	Electricity at work
4.	Moving things more easily	Lifting things more easily	How airplanes fly	Travelling on wheels
5.	Fire	Dissolving things	Common chemical changes	Living with the atom
6.	Reflection and refraction	How we see	Sunlight and plants	Photography
7.	Air around us	Air at work	Living in an ocean of air	Predicting the weather
8.	Watching the sky	Change of seasons	Neighbors of the earth	Locating places
9.	Some familiar rocks	Erosion of the land	Water and its uses	Importance of soil
10.	Animals in spring	Flowers and seeds	Life cycles of animals	Conserving wildlife

* A program modified to permit the use of more firsthand experiences and manipulative activities. Much of the material not covered in the seventh, eighth and ninth grades can be put in an advanced general science elective course. (Based on Table 13.)

physics course is no better for the non-academic minded pupil than is the whole course. And an eighth grade pupil with an inferior experience background will benefit little from the standard physics course even if he has very high aptitude. All special courses should be planned in terms of the pupils and what will bring them maximum benefit.

Suggested activities

1. Analyze a textbook as a course of study, looking for flexibility, adaptability to local situations, and appropriateness to grade level. What changes—additions, deletions and reorganization—might you make to fit the program to a specific teaching situation?

2. Examine a state or local course of study. Note the presence or absence of such features as seasonal arrangement, use of local resources and the like. What changes might you make in the organization to make it more effective?

3. Make a file of local teaching resources for the school in which you will do your cadet teaching. List possible field trips, outside authorities who may be called upon for help, occupations in which parents are likely to be engaged, and situations with which pupils are probably familiar.

4. Analyze the activities suggested by a textbook. In what percentage of the suggestions are the outcomes given directly or implied? Which of the activities encourage independent thinking? What suggestions may be modified to encourage independent thinking?

Suggested readings

Hall, Carrol G., "Learning Tours for Chemistry Students," *The Science Teacher*, February, 1950.

Peddiwell, J. A., *The Saber Tooth Curriculum*, McGraw-Hill, New York, 1939, pages 24-44.

A Program for Teaching Science, Thirty-first Yearbook of the National Society for the Study of Education, Public School Publishing Company, Bloomington, Ill., 1932.

Taylor, Wayne, "Industrial and Technological Resources Aid Science Teaching," *The Science Teacher*, March, 1951.

STANDARDS, EVALUATION, AND GRADING

chapter 16

This course is the hardest one I ever took but I like it." "I only got a C but it's my own fault; I should have worked harder." "He's strict but he's a wonderful teacher." "It's a good course. You have to work hard but you learn a lot."

Frequently heard comments such as these indicate that pupils like courses for which they have respect. They do not object to hard work providing they know they have chances for success. It is when they recognize that their chances for success are slim or nonexistent that they shun difficult courses.

Science teachers are faced with the problem of setting standards that make their courses challenging, without automatically failing large numbers of pupils. This country cannot afford a highly selective process that frightens all but a few from work in scientific fields. Neither can it afford mass education processes that hold all pupils to mediocre standards. A weak compromise has no place. What schools need are standards that are broadly conceived and applicable to the great range of pupils in the schools.

STANDARDS IN COMMON USE

For a number of years secondary school teachers have been at the focal point of much sharp criticism. They have been accused of lowering their standards and at the same time they have been accused of not attracting enough young people into scientific occupations. Many of

the criticisms are not based upon sound evidence. They are based upon opinions and upon vague recollections of conditions that existed twenty or more years ago. Actually, the record of science teachers has been good, though not as good as could be wished. A larger percentage of each age group is electing science courses today than ever before. Each generation of young people is better informed about science than the one before it. And judging by the quality of exhibits in science fairs, the achievements of the best of today's product will equal if not surpass those of yesterday's best.

Many of the criticisms have been inevitable and are the result of changing conditions. A few decades ago secondary schools were concerned chiefly with preparation for college. Today, secondary schools recognize an obligation to the large numbers of pupils who will not attend college. The change in emphasis, as might be expected, is lamented by college professors.

In addition, colleges today use a much broader base for determining admission qualifications than was used a few decades ago. As a result, college professors must work with a less homogeneous student body than they are accustomed to. They mistakenly attribute the change to the preparation their students have received in secondary schools.

A third factor that has resulted in criticism specifically directed at science teachers has entered the picture because of the expanding nature of the science field. In physics, for instance, time that could once be given to the solution of problems in mechanics must now be shared with a study of nuclear energy; the topic of internal combustion engines, once limited to gasoline engines, must now include Diesel engines, gas turbines, jet engines and rockets. In consequence, pupils in physics today have a less intensive training but a broader one.

Among the more justifiable complaints are those that concern the neglect of highly gifted pupils. As teachers have found themselves faced with pupils of increasing diversity in ability, they have allowed themselves to concentrate upon the pupils who presented the greatest problems. Pupils who could do the required work satisfactorily have received little attention.

Maximum standards. The work of secondary school pupils is usually judged by a narrow set of academic standards of the type that may be called "maximum" standards. These standards are set above the ability levels of all but the most able pupils and in consequence most pupils fall short of these standards. However, because teachers do not expect these standards to be attained, they accept as satisfactory a little less than the maximum.

Maximum standards operate successfully in relatively homogeneous groups. By accepting as satisfactory those achievements that represent 60 or 70 percent of the maximum, teachers make it possible for all pupils in the group to succeed. Slight differences in ability can be compensated for by extra effort and all pupils are in competition with each other.

However, as the ability range widens, maximum standards become less workable. In a group having a normal distribution of academic abilities, as represented by IQ's ranging from 80 to 130, as much as half the group fails automatically if the maximum standards are based on the ability of the most able pupils. There is then no incentive for large numbers of pupils. Competition is limited to the few most able individuals.

The strict application of maximum standards to heterogeneous groups has resulted in so many failures that science teachers have attempted compromises which have not been satisfactory. For one thing, they have tried lowering the level of the maximum enough to permit most pupils to succeed. The results have been unfortunate. The more able pupils are now without challenge; they can attain success without effort. They feel contempt for their courses and find no satisfaction in their high grades.

As another compromise, teachers have attempted to apply the normal distribution curve to the grades they give, thus insuring fixed percentages of high, low, and medium grades. Some injustices have been eliminated, automatic failure for one. On the other hand, new injustices have been introduced; no matter how hard a group works, or how little it does, the same number of pupils pass and fail.

"Marking on a curve," as it is called, is not sound statistically or in principle. The curve of normal distribution has statistical reliability only when applied to groups of several hundreds; its application to groups of thirty is ridiculous. Such marking eliminates in effect all standards; pupils have no definite objectives to work toward and no feeling of accomplishment; teachers have nothing by which to judge the effectiveness of their teaching and no incentive to make superior presentations.

Minimum standards. In some types of training, the standards that are set call for the complete attainment of all objectives. Since these objectives must lie within the ability range of all individuals concerned, the standards are of a minimum nature. Minimum standards are utilized in adult driver education courses; a student must become proficient in each qualification to pass; his achievement is not satisfactory if he applies the brakes properly only sixty percent of the time; he

cannot offset a lack of knowledge of traffic laws by superior performance at the wheel.

Minimum standards deny success to no one except the lazy, the indifferent, and the truly incompetent. They provide definite objectives towards which to work and from which a sense of accomplishment can be attained. Minimum standards put no ceiling on the work of superior individuals, but they do fail to give these last proper guidance in their work above the minimum.

Minimum standards could be used more extensively in the science program. There are a number of knowledges and skills, particularly in the areas of health and safety, that may be considered essential. These could be used in setting up minimum requirements that must be mastered for success.

Multiple standards. Teachers of vocational subjects commonly set up several sets of standards to operate in parallel, thus enabling a pupil's strengths to compensate for his weaknesses. A teacher of typing, for instance, has standards to judge proficiency with the typewriter, skills with handbooks and dictionaries, usage of grammar and punctuation, spelling ability, and ability to organize typed material. A teacher of vocational agriculture has standards to judge knowledge of theories and practices, skills with tools and equipment, ability to keep records, and success with project work.

Multiple standards are used to a limited extent in the academic phases of the science program but they could be applied much more broadly and much more extensively. Science is as broad a field as the vocational subjects, and there should be a place in it for a great range of abilities and talents. There should be standards to judge the acquisition of facts, standards to judge ability to communicate science understandings, standards to judge skills with science equipment, standards to judge abilities to keep records and use handbooks and tables, and standards to judge success with projects.

MAINTAINING STANDARDS

As has been shown, the problem of setting standards is particularly difficult for heterogeneous groups. As long as groups are relatively homogeneous, traditional maximum standards operate satisfactorily. It is for such subjects as general science, which take in all pupils, that new solutions are needed.

Using composite standards for heterogeneous groups. If science classes could be kept small and class loads light, the use of multiple standards would give an excellent solution to the problem of standards.

Each pupil could develop his special talents to the utmost and at the same time be credited for his successes. He would be able to explore his interests and abilities and emerge with an honest appraisal of himself, neither deflated for having failed to meet a narrow set of standards, nor inflated for having found success under ridiculously low standards.

With multiple standards there would be no necessity for lowering standards to reduce failures. Pupils who could not succeed in one way could find success in another. All standards could be kept high. Unfortunately, multiple standards require a free program and close supervision. Each pupil must be judged separately and on his own merits. With typical classes, science teachers do not have the time to use multiple standards exclusively.

Some of the advantages of multiple standards can be retained by using composites of two or more types of standards.

For many years Mr. Langer has utilized a composite of minimum standards and multiple standards in his general science classes. For each unit he lists a number of requirements which each pupil must fulfill completely. These requirements include facts to be learned, experiments to be carried out, reports to be written, and home assignments to be completed. Mr. Langer accepts no substitutes and does not deviate from the standards he sets for these requirements.

As soon as a pupil completes a minimum requirement, Mr. Langer encourages him to undertake additional assignments. Mr. Langer provides lists of suggestions from which pupils may choose. He also encourages his pupils to make their own suggestions, although he retains the power of veto. Mr. Langer gives full credit for all additional work and sets no limits to the amount that may be done.

Composite standards of the type used by Mr. Langer are both just and practical. The minimum requirements need but little supervision, leaving the teacher free to give individual help and encouragement as pupils complete their tasks. Classroom techniques need but little alteration save that more time is given for independent and small group work than is customary in the conventional program. A large share of the additional work is done outside school hours and requires little class time. Finally, the pupils recognize the basis for their grades and approve of it.

Setting minimum standards for heterogeneous groups. Minimum standards represent the very least that can be accepted as satisfactory. To be applicable, minimum standards should be within the abilities of all pupils. To be practical they should apply quickly and readily.

To be useful, they should apply to the type of work that challenges pupils.

Minimum standards fall generally into two categories. There are those that are satisfied by the mere completion of a task, as when a teacher requires each pupil to carry out a specified laboratory exercise. There are those that can be satisfied only by the display of some degree of proficiency, as when a teacher requires a legible and well-organized report of an experiment.

The second category of standards is concerned with knowledge and skills and is generally considered as more appropriate for the science program. However, the first category has usefulness in setting up minimum standards. After all, there can be value in merely doing things; laboratory exercises can be challenging even though required; diagram making can allow self-expression even though based on a chart; tables can be filled in with interesting data even though the data is taken from assigned readings.

Minimum standards applied to the acquisition of facts and understandings should be selected with the three levels of learning in mind—the mastery, recall, and recognition levels. Pupils should be expected to master only such material as is important enough to justify the special time and effort involved. Other material should be dealt with on the lower levels and judged appropriately.

There are a number of sources of help in setting minimum standards for factual learnings. Textbooks and courses of study list information commonly considered important. Tests represent another source of ideas. However, since these sources do not apply closely to any one situation, the teacher should consider them as suggestive only.

Under a strict interpretation of minimum standards each pupil should gain all required learnings to do satisfactory work; he should attain a perfect score on each test measuring minimum essentials. In practice, insistence upon perfect test scores is not realistic; scores a little short of perfection may be accepted.

Textbooks, courses of study, and laboratory manuals provide help in determining uniform assignments. Every effort should be used to keep these assignments from being routine and boring; challenging problems should be used whenever possible.

For those assignments that need only to be done to represent satisfactory work, there is no problem of setting standards; checkmarks on a checklist show whether or not pupils have met the minimum standards. If skills are to be developed, however, criteria for judging them should be set up ahead of time and announced to the pupils so that they have opportunities to practice these skills. Likewise, when reports and papers are to be prepared, pupils should be told frequently what

is expected of them so that they may have the points in mind as they work.

Helping pupils attain minimum standards. Once a requirement has been announced it is imperative that all pupils be held to the requirement lest they lose respect for both course and teacher. Threats and punishments, however, are poor stimuli; pupils respond better to encouragement, to help, and especially to success.

Frequent small tests used for review and drill are of great help in bringing all pupils up to the same level of knowledge.

Mr. Baker gave a ten-question review test dealing with cell structure. He made note of the most frequently missed questions and included these in a test a few days later. As the year progressed he occasionally included one or more of these same questions in tests until he was certain that all pupils could answer them.

The practice of repeating questions until all pupils have learned them is useful for teachers who are preparing pupils for the New York State Regents examinations and other standardized examinations. Teachers have found that by using two or three short tests weekly they insure success on the examinations and have the remainder of their class time for working towards broader goals.

It is well to allot a certain amount of class time for the beginning phases of all uniform assignments. During this time the teacher is free to move from pupil to pupil, interpreting directions, clearing up misunderstandings, and indicating the standards he expects the pupils to meet. Should it be necessary for the pupils to complete their assignments out of class, they work with more assurance for having had supervision at the beginning.

Class time may be allotted for make-up sessions to bring all pupils up to the same level of achievement.

Half way through the general science period Miss Lobdell made an announcement.

"Tomorrow," she said, "I will collect your notebooks and look over the section on weather prediction. Let's take some time now to see if you have all your required work."

As soon as the notebooks were opened she continued, "First you should have a title page. We worked on that last week. Next you should have a table of contents. I will give you time to make that later this period."

Miss Lobdell continued to specify precisely the titles and order of the pages she had required the pupils to make in their notebooks. She also suggested the most suitable locations for the various types of optional work many of the pupils had done.

"And now," Miss Lobdell concluded, "you may use the remainder of the period to prepare the table of contents and complete any unfinished work. Some of you may find it necessary to do some work at home tonight."

Pupils who have lost time because of sickness should be given special opportunities to make up their work. When possible this work should be done under supervision, perhaps during a free period, or during the class period while others are doing optional work. Commonly other pupils are qualified to help a classmate set up experiments or review for a test.

In any group there are apt to be pupils who do not do the work expected of them, usually because of lack of interest. Though the teacher should always try to use positive motivation there are times when these pupils must be compelled to do their work.

Compulsory make-up sessions are generally necessary, preferably at times inconvenient to the pupils. School policy varies as to when make-up sessions may be held but there is usually some provision for them. Teachers should treat make-up sessions as devices to help pupils pass their courses rather than as punishment. Threats to "keep pupils after school" do not frighten many pupils and may but make them more stubborn. Much more effective is a polite request to appear at a certain time for help in catching up with the others in the class.

During a make-up session pupils usually need a brief review of the requirements. They may have forgotten the assignment even if they were listening when it was made. They need the same help in beginning their work as they would have needed in class time.

Encouraging work beyond the minimum. After pupils have met the minimum standards that have been set for the class as a whole any further work they may do should be of a permissive nature. This does not mean that pupils may work or not as they please, but that they may choose the nature of the assignments they undertake. Thus there is opportunity for them to follow up special interests.

Uniform standards cannot be applied easily to permissive work; each case must be judged on its own merits rather than by comparison with what other pupils do. Rating is best done on a positive basis with pupils receiving credit for their achievements without penalty for weaknesses.

Special achievements fall in the following categories:

1. *Superior work on required assignments.* For example, all pupils have been asked to study vegetative reproduction using textbooks, films, and experiments, reporting their findings in their notebooks. One girl illustrated her report with clippings, colored drawings, and

diagrams giving more than fifty different examples of this type of reproduction.

2. *Investigation in depth of a required topic.* For example, all pupils were directed to make a study of the operation of a standard automobile engine, learning the function and operation of the major parts. One boy became interested in the fuel injection system of his father's automobile and studied it thoroughly. He read advertising literature, talked with mechanics, and studied the maintenance manual used in garages for the repair of this type of engine. He described his findings to the class, illustrating his talk with a chart borrowed from a sales agency.

3. *Acceptable work on a permissive assignment.* A chemistry teacher listed a number of demonstration experiments in the field of electro-chemistry. He asked each pupil to choose one demonstration-experiment from the list, or to suggest another, and to work up the demonstration for presentation to the class. Each pupil received a grade for his efforts.

4. *Voluntary work on suggested projects.* During a study of tone quality a physics teacher called attention to the difference in quality of the several reed instruments and suggested that some pupil might be interested in comparing the structure of these instruments. One girl, who played the clarinet in the high school band, volunteered to undertake this study.

5. *Voluntary services.* For example, a general science teacher took a photograph of a class project. Two pupils volunteered to prepare enough enlargements so that each pupil in the class could have a print.

6. *Independent work on teacher-approved projects.* A pupil read of a way to make rayon fibers from filter paper using only simple apparatus. He asked his chemistry teacher if he could undertake this project. The teacher not only gave permission but also allowed him to begin the project during the regular class period.

7. *Completely independent work.* An eighth grade girl had learned to make blueprints of leaves in a summer camp. She continued work on her collection during the summer and into the fall. When her science teacher heard of her work he asked her to exhibit her collection and describe her procedures.

8. *Shared experiences.* A seventh grade boy watching television saw an experiment with magnets and iron filings in water. He tried the experiment at home and asked his science teacher if he could show the experiment to the class.

9. *Shared materials.* While on a trip into nearby mountains a boy collected several "books" of mica. He gave several sheets to each pupil in his class so that the structure could be examined closely.

Teachers must expect to provide time and facilities for permissive work just as they provide time and facilities for uniform assignments. During part of a period pupils may be working towards minimum objectives; during the remainder of the period they may be working on permissive assignments. Some homework assignments may be directed towards meeting minimum objectives; others may be completely permissive in nature.

All pupils should be expected to do some work beyond the minimum. Even seriously handicapped pupils who find minimum requirements too much for them can do additional work, usually of a non-academic nature. In many cases teachers may find it necessary to provide suggestions and even specific directions.

Pupils need special recognition for all work they do above the minimum. Grades are inadequate measures at best and difficult to explain to pupils. Merited praise from the teacher and opportunities to display achievements to other pupils are usually sufficient. Superior work can be acknowledged through special displays, radio and newspaper publicity, and competition in science fairs.

Evaluating work beyond the minimum. All permissive work should be given credit toward the final grades of pupils. However, because uniform standards cannot be applied, a teacher must judge each item separately and subjectively. If he evaluates only on a positive basis, giving credit for accomplishments, it is not likely that he will be unfair to individual pupils.

Learnings above the minimum requirements can be measured in part by suitably designed tests. One form of test is constructed with two parts, the first measuring mastery of the minimum requirements and the second part, which allows choice of questions to be answered, measuring learnings above the minimum. A variant on this form of test uses bonus questions which a pupil may choose to answer if he feels he can earn extra credit.

Tests may be constructed with a broad range of questions so that pupils who have explored special fields may find material they have studied. With such a test a satisfactory grade may be represented by a score of fifty or sixty percent of the total. Greater achievement is represented by higher scores.

Pupils may volunteer to take tests for extra credit. These may be tests constructed by the teacher; but because teacher time is limited, tests found in textbooks, workbooks, and review books are more often used. Pupils preparing for college board examinations or other standardized tests may concentrate on this type of test.

Extra notebook work should be judged by several standards operat-

ing in parallel. Points that should be considered are: thoroughness, organization, accuracy, handwriting, spelling, grammar, care with diagrams and labels, wise use of illustrative materials. Some teachers insist that all additional work be pertinent to the topics studied in class; other teachers encourage pupils to include material on current events, special investigations, and matters of special interest to the pupils.

Library research projects may be rated upon the number of sources used, the thoroughness of investigation, the organization of data, the treatment of conflicting points of view, and the quality of the summaries. Written reports may also be rated upon handwriting, spelling, grammar, and documentation.

Experimental research problems should be rated in terms of originality, statement of problem, thoroughness in collecting data, organization and summarization of data, and carefulness in reporting findings. Special attention should be given to the conclusions drawn and the attempts to substantiate the conclusions through further investigation.

Demonstrations presented by pupils may be rated according to the amount of preparation involved, the presentation of the problem, the organization of the data collected, and the conclusions drawn.

Construction projects may or may not involve original planning; some projects represent no more than the assembly of commercial kits, others represent the step-by-step following of prepared plans, still others represent complete planning on the part of the pupils. Some projects are preceded by extensive research; this research adds to knowledge and deserves recognition. Teachers should remember that large spectacular projects may not represent as much investigation, experimentation, and problem solving as smaller, less conspicuous efforts. Additional points to consider are the skills with tools and materials, attention to details, and ingenuity displayed.

Teachers should not forget to give credit for the many lesser contributions of pupils, care of classroom plants and animals, voluntary distribution and collection of materials, help with cleaning glassware and organizing apparatus, and assistance with bulletin boards. Pupils who serve with distinction as group leaders, secretaries or in other capacities deserve recognition also.

The problem of grading for "effort" always arises. Should pupils receive extra credit for sheer volume of their work even though the quality seems low? The criterion to be used in evaluation is the benefit to the pupil. Many activities represent important learning situations even though tangible results are difficult to demonstrate. A teacher will not perpetrate many injustices if he errs on the side of generosity.

Another problem that arises in evaluation is the basing of credit on ability. Should a pupil of high ability receive as much credit for a

piece of work as a less able classmate who does work of the same caliber? Ability is a very hard thing to measure and attempts to do so adds another variable to the already confusing problem of evaluation. However, there may be times when a teacher feels justified in giving one pupil unusual credit for a mediocre accomplishment while refusing another pupil credit for an equally mediocre accomplishment. The effect upon the pupils involved is the most important thing to be considered; the teacher must be careful not to seem unjust in his judgment.

MAKING GRADES CONSISTENT WITH STANDARDS

The determination of grades is a serious responsibility. Grades, once entered in the records, have great impact on the lives of pupils. They represent success or failure with all the attendent emotions. They are used to compare one pupil with another. They are used to determine readiness for promotion and graduation and fitness for college or other advanced training. They are taken into account in awarding scholarships and in deciding upon employment. It is unfortunate that so much weight is given to grades because there are no truly objective measuring devices that can be used in determining them. Grading must be largely subjective in nature.

The more factors that a teacher can take into consideration in grading the less likely it is that he will commit injustices. Grades based on tests alone, for instance, do not give as good a picture of achievement as grades based on reports, research, projects and tests.

Types of achievement. Certain types of achievements can be evaluated with some degree of assurance. These achievements fall in the following categories:

1. *Learnings that can be measured by tests.* These include word meanings, statements of principles, recognition of applications, and solution of verbal problems. Learnings that are difficult to measure include understandings of complex situations, understandings that do not lend themselves to verbalization, appreciations, and attitudes.

2. *Skills that can be demonstrated quickly.* These include skills with reading, with mathematical processes, with the use of books, tools, and equipment. Difficult to measure are such skills as problem solving skills.

3. *Completion of assigned tasks that are simple in nature.* It is relatively easy to check off tasks such as laboratory exercises, mathematical exercises, and workbook activities as soon as they are completed.

4. *Certain aspects of permissive work.* Reports and projects carried out by pupils under the supervision of the teacher can be evaluated in terms of the end products and in terms of such procedures as are observed. It is difficult to determine many of the major benefits to the pupils.

5. *Tangible results of independent work.* The end products of independent research and of independent project work can be evaluated. Unless part or all of the work has been done in the classroom the procedures cannot be evaluated. The major benefits to the pupils cannot be evaluated.

Keeping records of achievements. Full records are essential for arriving at grades. It is difficult to remember the nature and extent of each pupil's achievements, especially in the case of pupils who work quietly and without spectacular results.

Record forms should permit notations as to the different types of achievements pupils may have. A portion of a record book adapted for science records is shown on page 423. There are four major headings:

1. *Quizzes and unit tests.* Several spaces are reserved for the scores of short tests. A few spaces are reserved for the scores of longer tests and unit tests.

2. *Assigned work.* This section is treated as a check list except that grades are given for work which surpasses the minimum.

3. *Permissive work.* In this section are entered the grades given for optional assignments carried out as part of regular class work.

4. *Voluntary work.* In this section are recorded the grades given for work that pupils undertake spontaneously and do largely on their own time. There may be no entries in this section for some pupils and only a few for others.

A record book is convenient to carry about and store. The records are compact and easily examined. However, there is not enough space to specify the nature of the achievements indicated in sections 3 and 4 above. In consequence a busy teacher has difficulty in calling to mind precisely what each pupil has done; he is handicapped in arriving at final grades.

On page 425 is a sheet from a standard 8½″ by 11″ notebook in which one teacher keeps his records of the voluntary work done by his pupils. This form, which the teacher makes in quantity with a duplicator, has spaces large enough for brief notations of each activity carried out. When determining grades he skims over the sheets to refresh his memory.

Some teachers prefer to keep their records on filing cards despite the problems of carrying and storing cards. The front of a card is

A TEACHER'S RECORD BOOK

Name	Quizzes						Unit test	Assignments			Permissive			Voluntary			Average
Alton, Patrick	9	8	9	7	6	8	78	√	√	A	B	B	C	B			
Carra, Richard	7	8	a	7	8	8	75	√	B	√	C	C	C				
Cockfield, Nancy	10	9	10	10	10	10	95	A	A+	A+	A	A+	A	A+		A	
Coulter, Roxanne	8	8	7	a	a	7	82	B	√	B	A	B	A				
Crosby, Ralph	4	6	3	6	6	3	40	√		√	D	D	O				
Davis, Edna	7	9	7	7	7	6	80	√	√	√	A	A	A	C		C	
Dodge, Robert	10	10	10	8	8	10	100	A	B	B	B	B	A				
Enell, Carl	6	7	7	10	6	6	45	√	√	B	C	A	C	C			
Griffen, Faith	7	4	8	6	6	7	63	√	√	√	D	D	A				
Harris, Robert	9	8	7	9	9	4	85	A	√	A	E	D	D				
Ikeda, Vivian	8	8	8	9	8	9	94	√	B	√	A	B	A				
Jackson, David	6	3	6	6	2	a	48	√	√	√	C	D	C	C	C	D	
Jorden, Christine	10	7	10	8	9	10	95	√	√	√	D	B	D				
Lawrence, Joanne	5	6	5	8	6	7	64	√	√	√	D	D	D	A+			
Lindop, Kathryn	0	8	7	9	7	7	81	B	√	B	C	C	B	C			
Mason, Donald	a	a	a	a	9	9	95	a	√	a	a	a	C	B			
Miller, Jane	7	8	8	4	8	8	82	√	√	√	B	B	C	C		C	
Miller, June	9	8	7	9	8	7	88	√	√	√	B	B	B	C		C	
Monahan, Michael	8	9	10	10	6	4	51	√	√	√	A	C	D				
Motley, Louise	10	7	6	8	10	9	98	B	A	√	A	C	A				

used for test grades and notes on other achievements. The reverse is used for notes on conferences and for observations of behavior.

Assigning grades. When records are kept in the above fashion, final grades are determined by combining all the results of a pupil's work. Test grades are averaged, with long tests being given more weight than short tests. For example, if a test that ends a unit is three times as long as a typical quiz, the score on that test is tripled before averaging it with the others.

Grades for required work and for permissive work are then averaged, proper weight being given according to the nature of the difficulties involved in each assignment. These results are combined with the test average to give a tentative final grade.

There are a number of ways for handling the credit given for voluntary work. Some teachers include the grades in with the permissive assignments. Other teachers work out a system for raising the final grade a certain number of points for each voluntary activity, the amount of increase depending upon the grades earned in each case.

It is sometimes convenient to use numerical grades for tests and letter grades for other achievements. A conversion table is then needed. Each teacher should construct his own to fit his method of scoring. A conversion table that is commonly used is shown below:

Score in percent	*Letter grade*	*Significance of grade*
90 to 100	A to A–	Superior
80 to 89	B to B–	Good
70 to 79	C to C–	Fair
60 to 69	D to D–	Satisfactory
Below 60	E	Unsatisfactory

The method of amalgamating grades in determining final grades helps to reduce some of the injustices that are bound to result when test grades alone are used. With this process the highest grades are reserved for the pupils who excel in tests and who exert themselves to do superior work. Pupils who pass tests easily are not penalized for failing to work but they are denied superior grades unless they do more than the minimum. Pupils who have special aptitudes but lack all around excellence can earn high grades by exploiting their special talents. Pupils who lack academic ability and find tests difficult can still earn satisfactory grades by sufficient hard work. Only pupils who lack ability and refuse to try are certain of failure.

A TEACHER'S RECORD OF VOLUNTARY WORK

Names								
Book report								
Article report								
T. V. science								
Radio science program								
Interview								
Watched or worked with scientist								
Radio-T. V. broadcast								
Class report								
Class demonstration								
Exhibit								
Bulletin board								
Project								
Research								
Wrote news article								
Field trip								
Other								

(Courtesy of Walter DeNeef, Dryden Central School, Dryden, N.Y.)

Suggested activities

1. Make up a set of minimum requirements for a unit in general science, assuming a heterogeneous group of students. Be sure that the requirements are realistic—that the learnings justify the time needed for mastery, that each requirement lies within the abilities of each pupil, and that there are not more requirements than can be attained within the time allotted for the unit.

2. Write out suggestions for activities in which pupils might engage after they have completed the minimum requirements for the unit just mentioned. Try to find suggestions to meet a wide variety of interests and abilities.

3. Work out final grades for the pupils whose test and project grades are given on page 423. Compare your grades with those worked out by other prospective teachers. Defend your basis for grading.

Suggested readings

Dunning, Gordon M., "Evaluation in Science," *The Science Teachers News Bulletin*, April, 1947, pages 5-8, 34-39.

Niessen, A. M., "Marking on a Curve," *School Science and Mathematics*, February, 1946, pages 155-158.

Spear, W. W., "Remedial Instruction," *School Science and Mathematics*, December, 1946, page 807.

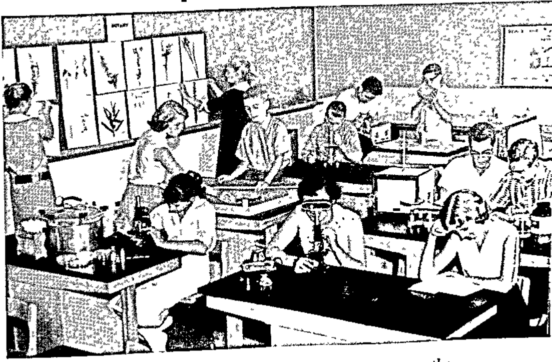
Thomas, R. Murray, *Judging Student Progress*, Longmans, Green, New York, 1954.

Weaver, Edward K., "Evaluation of Student Achievement in Science," *Science Education*, March, 1948, page 81.

Yothers, Lee R., "The Practicum for Testing Science Learning," *Science Education*, March, 1949, page 124.

Part IV

Making the most of the science program



The more the science teacher can individualize his program, the more he can do for his pupils. As pupils follow up their special interests, they discover their strengths and weaknesses, develop their particular talents, and learn the satisfaction that can come through achievement.

PROVIDING EQUAL EDUCATIONAL OPPORTUNITIES FOR ALL

chapter 17

The greatest challenge in education today is the development of means whereby each young person can progress at his maximum rate as far as he is able to go. Completely individualized instruction is too expensive. Mass instruction techniques, though providing equal schooling opportunities, are unjust to pupils who should progress more rapidly or more slowly or in other directions. The European system of isolating young people in rigid groupings is not compatible with American democracy. Acceleration and retardation by grades brings in many social adjustment problems.

Within the science program, educational opportunities can be equalized by various forms of grouping and by limited individualization of instruction, both of which can be applied within moderate sized heterogeneous classes. When facilities permit, small groups of especially talented youngsters may be isolated temporarily in classes geared for their particular abilities.

IDENTIFYING ABILITIES AND INTERESTS

Pupils can be provided for only when the teacher knows them as individuals—their interests, their personality traits, their abilities, their backgrounds, and their specific needs. Obviously no teacher can come to know his pupils as well as that by direct acquaintance unless he is fortunate enough to teach in a small school system where he works with the same individuals year after year. He must usually depend upon other sources of information.

Counseling records. Records of each pupil are usually kept in the guidance office of a school. If there is no guidance office these records will be found in the administrative offices. Among the records are the results of standardized tests. Of special value are the intelligence test scores, the mental ages, the reading levels and the general achievement levels. Scores on any standardized science and mathematics tests may prove useful. Grades give a measure of a pupil's performance in school and a clue to his reaction to academic work. The same records tell which courses he elected and how well he did in each.

The data in the guidance office are more useful in locating problems than in finding answers. The records show which pupils should be doing better work, but tell neither why they do not nor how to help them. Low intelligence test scores do not explain low grades; they point only to a common factor causing both.

The personal data questionnaire. Many teachers prepare a questionnaire which they ask pupils to fill out the first day of school. The information on interests and backgrounds is of value in making plans to utilize special interests and experiences. A personal data card used by the science teachers in one school system is shown on page 431. This particular card also provides space for other data—standardized test results, grades, and records of special activities.

Personal contacts. Most of a teacher's acquaintance with his pupils comes as he works with them in the classroom. With mass instruction techniques only the extremes stand out—the enthusiastic and the actively noncooperative. The more that a teacher can individualize his instruction the better he comes to know the pupils as individuals and the better he can meet their special needs.

Closer acquaintance is gained during such out-of-class work that the pupils might engage in—science projects, science clubs, and other activities in which the science teacher may have a part. In activities out of school, such as scouting, the teacher comes to know his pupils as they really are, away from the artificial environment of the classroom.

To help themselves identify their pupils better, many teachers keep brief notes on special characteristics. These may be kept in a card file, on the personal data questionnaire, or in a notebook.

Conferences with other teachers. Any teacher who has had previous contacts with a pupil has important information about him—his special abilities, his interests, and his background. Unfortunately this information cannot be passed along as readily as are his grades.

In large systems, a science teacher cannot interview all the former teachers of each of his pupils, but he can contact them about special

PERSONAL DATA CARD

(Last name)	(First name)	(Section)	(Homeroom)
(Street address)		M.A. ______	
(City)		R.L. ______	
(Birthday)	(Age)	A.G. ______	
(Father's name)		*(Occupation)*	
(Mother's name)		(Occupation)	

If you have lived in other cities or states, tell where.

Give the names of some of the places to which you have travelled.

What kinds of work have you done for pay?

What are some of your hobbies?

To what organizations do you belong? What offices have you held? What is your rank (in scouts)?

What kinds of movies, radio programs and television programs do you like best?

What kinds of reading do you like best?

What is the name of a book you have read recently?

What magazines do you take at home and read regularly?

problem cases. Information gained must be interpreted with caution because teachers, being human, develop prejudices and may do injustice to certain pupils.

Sociograms. Knowledge of the social structure of a class may be helpful in discovering cliques, rejects, and antagonistic individuals; such information is needed in planning group work. Social structure can be determined in part by the construction of "sociograms." Each pupil in

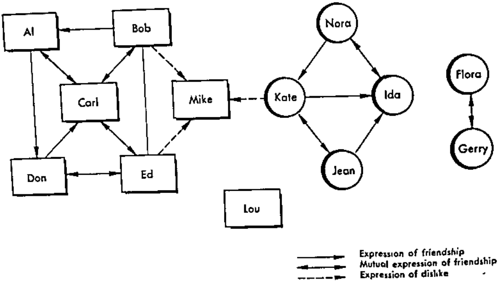


FIGURE 16. *A simple sociogram, showing two cliques, one friendship pair, one isolate, and a reject. Boys are represented by squares, girls, by circles. In making the sociogram, the teacher asked the pupils to indicate strong dislikes, as well as likes. However, it may not be wise to ask for expressions of dislike.* (Adapted from W. W. Wattenberg, *The Adolescent Years*, Harcourt, Brace, New York, 1955.)

a class is asked to list the names of his three (or four) best friends in the class. From the data the teacher builds a chart like that shown in figure 16. Circles represent girls; squares represent boys. Arrows leading from one symbol to another indicate an expression of friendship; a double arrow represents a mutual declaration.[1]

Sociograms must be used with caution. They do not tell everything and they can be misinterpreted. At best they represent fleeting conditions. The teacher must supplement them with his own observations.

EMPLOYING GROUPING IN THE SCIENCE PROGRAM

Grouping is not new in the science program. For many years science teachers have divided their classes into teams of two or three for

[1] For more information on the construction and use of sociograms see: Jennings, H. H., *Leadership and Isolation*, Longmans, New York, 1943.

laboratory work. However, such grouping has been employed more often in the interests of convenience than with the full potentialities of grouping in mind.

Contributions of grouping. Grouping, when properly employed, produces a number of beneficial outcomes:

1. Allows full participation by the individual
2. Gives maximum direct experience with materials
3. Provides for wide range of interests
4. Provides for wide range of talents
5. Permits close matching of assignments to abilities
6. Takes advantages of adolescents' desire to work together
7. Gives shy and retiring pupils increased security
8. Gives practice in democratic processes
9. Helps pupils explore their leadership potentials
10. Provides a change from standard classroom techniques
11. Helps teachers become better acquainted with individuals
12. Helps teachers find time for special help for individuals

Not all of the above benefits will be operative at the same time. However, the teacher can usually plan for several of them in any one grouping situation.

Some considerations in setting up groups. A little knowledge of the general nature of preadolescents and adolescents helps the teacher organize his groups wisely. Preadolescent boys, for instance, usually object to being paired with girls. Many adolescents rebel when required to work with someone they consider unacceptable; the problem of the reject must be given careful forethought.

Two or three persistent troublemakers, taking advantage of the relative freedom of group work, can upset an entire class. Teachers are apt to separate these individuals, a technique which is successful as long as each is accepted by the group to which he is assigned and finds worthwhile things to do. Commonly, however, these individuals are ignored by their teammates and gradually drift back together again.

Sometimes it is well to put these individuals, who are generally of the same age, mental ability, and interests, into one group to work on a problem equated to their special interests and abilities. They often do better together than when forced to work with pupils who have been more successful in school than themselves.

Mr. Woodhull, a cadet teacher, had been warned not to group Chuck and George together. But he forgot the warning and allowed them to team up in constructing a telegraph set. To everyone's surprise, the boys worked with all seriousness and were heard to complain when other groups became a bit frivolous.

To care for the reject, the teacher should try to find one or more secure individuals who are willing to choose him as a member of a group. Sometimes a private conference beforehand, with the problem presented honestly to them, is sufficient to gain their cooperation.

Good leaders are needed for groupings of three or more. Haphazard assignment of leadership responsibilities may give difficulty, especially if a "clown" or a "slave" is put in charge of a group; many pupils will refuse to work under unacceptable individuals and many pupils will not know how to accept leadership responsibilities.

Attention must be given to providing each member of a group with worthwhile things to do. If an experiment can keep but three pupils busy at the same time, the group should contain no more than three members. If there are only two books available for a reading project a teacher is inviting trouble if he assigns more than two pupils to the group.

Most groups of three or more require some help with organization. Adolescent leaders have not had enough experience to recognize the importance of assigning suitable responsibilities to each member of their respective groups. They tend to do too much themselves and they fail to share the problems of planning. A teacher must expect to give help with assigning responsibilities, especially if assignments are at all complex.

A teacher should not be discouraged if grouping procedures do not come up to his expectations. For one thing, he is dealing with individuals who have minds of their own; no group activities will go exactly as the teacher has planned. For another thing, secondary school pupils are just learning group processes; in many systems they have been given no practice within curricular boundaries. Failures are inevitable. But failures should not end grouping; the pupils probably need more experiences in simpler situations. Refusal to grant them these experiences will delay their growth.

Using detached groups. The practice of detaching a small group of pupils from the remainder of a class to undertake special work has much to recommend it. The pupils selected usually have high interest in the problems. They work with enthusiasm. They need little supervision.

Gifted pupils benefit especially by detached grouping. They accomplish regular class assignments in a fraction of the time needed by their classmates. They need additional problems to challenge them while the remainder of the class is catching up.

Interestingly enough, retarded pupils also benefit from detached

grouping. In such group work they find problems that enable them to use any special skills, usually manipulative in nature, that they might possess. The teacher must recognize, however, that work on such problems does not help retarded pupils pass pencil-and-paper tests to which they might be held; they will need special help if they are required to pass these tests.

Detached grouping always has permissive aspects. Perhaps a teacher calls for volunteers to undertake a special project.

"I would like to have some models of synclines and anticlines like those shown in the textbook," the earth science teacher announced. "Would anyone like to try making them?"

Two hands were waved vigorously. The teacher made an assignment to busy the other pupils while he met with the two volunteers to plan their course of action.

Once pupils are accustomed to the practice of detached grouping they commonly propose their own problems on which to work.

The biology teacher was approached by three classmates during the interval between classes. "Miss Pfitzer," said the spokesman for the group, "Suzanne, Betty and I are interested in the experiment you told about yesterday—the one where you put hormones on slips to make the roots come out faster. Do you suppose we could do that?"

The teacher may also appoint a committee to undertake a special task which seems of value to the individuals.

Mr. Cummings ended a discussion on skin diving by making an assignment to the boy who had shown the most interest. "Chester," he said, "will you choose a couple of your friends to find out more about the effects of pressure on divers? You can work at the back of the room and we will listen to your report tomorrow."

It is possible to detach more than one group at a time. However problems of supervision increase rapidly as the number of detached groups increases. If a teacher must conduct regular classwork and at the same time give help to two or more groups working on entirely different topics, he may find the situation difficult.

Simple pairings. For many types of laboratory and field experiences grouping by pairs is effective. Individual participation is insured in such small groups and organizational problems are minor or lacking. Commonly classes are divided into teams of two for work on uniform assignments. There are advantages to having pupils work on the same

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However, as pointed out previously, larger groupings demand special planning. Leaders must be selected with care. Worthwhile responsibilities must be available for each member. And leaders need help in assigning responsibilities.

Mr. Watson, a student teacher, planned germination experiments for group work. He arbitrarily divided the class into five groups of six pupils each, gave them the needed materials and told them to go to work.

The responsibilities involved divided themselves naturally into three parts. Three pupils in each group assumed these responsibilities but no one tried to find suitable occupations for the remaining members. Some of the unoccupied pupils watched passively, some discussed matters of personal interest with each other, and three of the older boys became disturbing influences.

Mr. Watson could have avoided this problem in one of two ways. He could have provided more materials and set up ten groups of pupils instead of five. Or he could have retained groupings of six and given help in organizing the activities of each group.

The amount of organizational help groups need depends upon the nature of the problems undertaken. With simple activities, pupils readily set up their own groups, choose leaders, and plan their courses of action.

After a marine-life collecting trip, Miss Harrington asked her pupils to divide themselves into groups and take care of the specimens, one group cleaning up the gastropod shells, another group pressing algae, a third group putting coelenterates in preservative, and so on.

For more complex problems, attention must be given to the selection of group personnel and the allocation of responsibilities. Each group must have a leader with whom other group members will cooperate. If special skills are called for, the teacher must use his influence to see that each group includes pupils having these special skills.

A teacher may find it wise to select leaders in advance for problems that are unusually complex and when much depends upon the activities of the leaders. The teacher may also give leaders detailed suggestions for group organization.

Mr. Wilson announced that for an experiment with vacuum tubes the pupils would work in groups of threes, one varying the grid voltage, the second

problems; materials can be prepared easily and supervision is relatively simple.

It is also possible for each pair of pupils to work on different problems. This makes it possible to equate the assignments to the abilities and interests of the pupils. The usual technique for making the assignments is to prepare a list of suitable problems from which each pair chooses the one it wishes to work on. The teacher may also permit pupils to propose related problems in place of those on the list. The major disadvantage of using different assignments lies in the difficulty of preparing materials for so many situations. Some topics lend themselves more satisfactorily to this technique than do others.

Mr. Morrone's eighth grade science classes were studying solutions. At the beginning of the period, Mr. Morrone demonstrated the use of a filter in distinguishing solutions from suspensions. He uncovered a large assortment of samples on his front table and asked the pupils to choose partners and test two or three of the samples for solubility.

In this case, Mr. Morrone gave his pupils the privilege of choosing their own partners. Many teachers prefer to make pairings on an arbitrary basis to control the nature of the groups. There are times when this latter practice is justified but the pupils are denied opportunities for taking responsibilities for their own behavior.

When pupils are allowed to choose their own partners, a certain amount of noise and confusion must be expected. This can be kept within an interval of short duration by proper planning. If the pupils understand clearly the problems they will undertake and the procedures they will use, most of them will go to work as soon as they have chosen their partners. The teacher should keep himself free of other responsibilities during this interval to give attention to any pupils who do not tackle their problems immediately.

Because pupils work at different rates, there should be some provision for groups that complete their assignments early. Additional investigations may have been proposed during the planning process. Or the teacher may make suggestions to individual groups as each completes its task. It is also possible to provide in advance individual reading or notebook assignments to be worked on as soon as the group assignments are fulfilled.

Groupings of three or more pupils. Within the larger groups the social structure is much more realistic than in groups of two. The impact of different personalities is stronger. There is more give-and-take and more compromise. Special talents can be given more adequate recognition. Leadership calls for more than mere aggressiveness; leaders must have tact, diplomacy, and consideration for others.

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noting the plate current, and the third keeping records. He selected six pupils to serve as leaders and asked them to choose the other members of their respective groups and assign the responsibilities.

Sometimes a teacher may find it wise to meet with the group leaders beforehand to work out the membership of the groups.

Mr. Kane planned six different tropism experiments to be carried out by an equal number of groups. He chose six pupils of demonstrated leadership ability and conferred with them while the remainder of the class worked on a special assignment.

Mr. Kane outlined the experiments and the methods of attack. He suggested a pattern for group organization, proposing that each group have a chairman, a secretary for taking notes, an artist for making diagrams, an experimenter to do the manipulative work and an experimenter's helper to assist him. The leaders accepted his suggestions and after discussing the qualifications needed for each job, set up the group membership so that these qualifications were provided for.

Because many secondary school pupils have had little experience with grouping procedures, the beginning teacher is advised to move slowly in utilizing groupings of three or more. He may start with simple pairings and with detached groupings and as experience grows he may add the third member to the groups, giving detailed help in organization. Gradually, as pupils develop suitable skills they may be given additional responsibilities. The ultimate will be reached when they suggest their own problems, organize themselves into groups, and plan their own methods of attack.

HELPING PUPILS WORK ALONE

Most adolescents are highly gregarious and find security only in the company of their fellows. And yet they need opportunities to explore their capacities to work alone; some of them may find in completely independent work their greatest challenge. The science program should be organized to include short periods of independent work with plentiful options for pupils to continue working alone in follow-up activities. In addition, the teacher should constantly extend invitations for pupils to undertake projects that are not related directly to classwork.

Individualizing classroom instruction. The vision of a group of pupils working independently, each beginning at the point to which he had already progressed and continuing as rapidly and as far as his abilities permit, is one that has long intrigued educators. Continued

experimentation, however, has not produced techniques that continue to be used on a large scale in American schools.

Truly individualized instruction can be successful only when personal tutoring is possible, and with individuals who have strong incentives for learning as well as knowledge of how to obtain information. These are conditions rarely encountered in public secondary schools. Many compromises are necessary.

Easily supervised activities based on reading and writing lend themselves well to individualized instruction. Science notebooks provide excellent independent learning situations.

Mr. Shaver's earth science class was made up of ninth grade pupils of exceptionally high ability, all excused from the standard general science course to enter this small, select section. Mr. Shaver provided duplicate assignment sheets listing fifteen questions on astronomy. The first of these called for little more than recall of learnings in previous grades. The problems became increasingly complex and the last few called for extensive library research. The pupils undertook the assignment with high zest, doing much work outside school hours. Most of them completed all fifteen tasks although this was not required; all pupils did the major part of the tasks.

This type of work appealed strongly to this special group of adolescents. It would not have equal success with unselected groups in which there are pupils who do not find reading sufficiently rewarding. Variety is needed for most pupils—experiments, project work, field trips, as well as reading and making reports.

Mrs. Abernathy duplicated a set of questions for her pupils to answer, listing suitable references, and announced that as soon as the pupils had completed this assignment they could read farther on any topics that interested them, or try out experiments described in the reading, or undertake special projects associated with the unit.

One boy, an avid reader, was able to answer the questions without reference to books. Most of the pupils completed the work within half a period. A few needed a longer time.

Mrs. Abernathy's technique contains some of the elements of completely individualized instruction and yet is practical within the usual classroom situation. First of all, there is consideration for the backgrounds of the pupils—further reading is not required if pupils already know the answers. There is freedom to work at different rates. There is incentive to work at the maximum rate—at least for those pupils who are challenged by the optional tasks. And there is provision for pupils to go farther than the minimum.

nathy started all pupils at work at identical tasks making up a minimum assignment which required little supervision. Thus she was free to give special help to any who might need it. And as pupils began to complete the assignment, usually at different times, she was still free to help them get started on new tasks.

Ideally, individualized instruction in science should make provisions for laboratory and field work. Practically, because of size of classes and problems of supervision, more compromises are necessary. Sometimes small group laboratory exercises can be blended with individualized instruction of other types.

Mr. Marsted asked his physics pupils to complete two laboratory exercises dealing with the measurement of voltage and current. These were to be followed by assigned readings and mathematical exercises. After the minimum requirements were completed, pupils could undertake additional laboratory work or reference work. Pupils were asked to work in pairs for the first two exercises but to work alone thereafter.

An essential feature of all individualized instruction is frequent testing. Pupils must know how well they are progressing. The teacher must know when additional work is needed and when pupils are ready to undertake new tasks. Because pupils are in different stages of progress, testing must be done on an individual basis. Therefore tests must be easy to administer and simple to evaluate.

Self-administered and self-evaluated progress tests are distinctly advantageous. Pupils like performance tests and identification tests of this type. When pencil-and-paper tests are used, the questions should be of the type that permit only one correct answer lest the pupils find it necessary to turn to the teacher frequently for help in scoring.

It is well to provide two or three forms of the same test. A pupil who fails the first test, does additional work, and returns for retesting can be given the second form. This reduces the "carry over" effect when the same form is used twice.

When the teacher wishes to test progress himself, he should use tests that can be scored quickly. If the work of the pupil is in tangible form a single glance is sufficient; one look at a simple electric circuit or a bend in glass tubing tells how well a pupil has done. Skills in reading weather maps, contour maps, and the like can be determined quickly.

Mr. Puzilla wrote on his own copy of a contour map the height of certain hills and the distances between certain points. In testing a pupil's ability to read a topographic map, Mr. Puzilla was able to check answers quickly.

Pencil-and-paper tests are apt to require more time for scoring and the teacher is apt to be interrupted frequently in the process. If he confines his test to diagrams or to easily memorized sequences of numbers, he can limit scoring to a quick scanning and reduce the necessary time to a few seconds. (See chapter eleven for quick scoring techniques.)

Oral testing is the preferred method for determining progress because this allows the teacher to analyze the pupil's strengths and weaknesses in order to suggest remedial procedures. Oral questioning introduces some problems of time and privacy. The time element can often be reduced by asking first a few sampling questions and exploring only the areas in which deficiencies seem to be revealed by the answers.

Mrs. Wilbur tested each pupil's knowledge of anatomy by pointing to organs in a dissected cat with the expectation that the pupil could give the names and functions of those organs. She discovered that the pupil who could give correct answers to the first three or four questions usually did as well on additional questions of the same difficulty. She developed the practice of limiting her oral tests to four questions except for pupils who revealed deficiencies; these latter pupils were tested more thoroughly.

Encouraging independent work. Independent work carried out either as an outgrowth of the regular program or unrelated to it is a form of individualized instruction. Chapter twelve (page 314) describes the case of Alice, and the benefits that came because her general science teacher permitted her to use part of her class time to explore an interest in butterflies. There can be no question that Alice gained in terms of understandings, skills, and attitudes even as she might have under the regular program; there is considerable evidence that she actually gained far more.

Many teachers would have refused Alice so much freedom. They would have insisted that she view the same demonstrations, prepare the same reports and sit through the same discussions. Many other teachers would have granted freedom reluctantly, permitting her to do independent work only after the completion of all assignments. But fortunately for Alice, her teacher was more concerned with her as an individual than with the uniformity of his program, and he did not require of her the same assignments that he required of others.

Pupils who have the ability to do independent work usually grasp the basic material of a course in a fraction of the time needed by their fellows; they can work on special assignments while their fellows are catching up with them. Even when they lose out on some of the planned learnings of a course, the material they do learn is usually

of equal value. It is difficult to imagine that any pupil is harmed by being allowed to follow up some special interest in science.[2]

A teacher must not expect pupils to undertake independent work spontaneously. Few pupils are accustomed to so much freedom. They do not have the background to recognize challenging problems. They need much help in defining problems, in planning methods of attack, and in overcoming unexpected difficulties. A teacher will find that for weeks at a time no pupils will be working on independent projects and he will rarely find more than a small percentage of his classes so engaged at any one time.

The teacher must expect to provide most of the ideas for independent work. Many suggestions will arise from regular class work.

During an eighth grade unit on gardening, discussion turned to the hardiness of various garden plants. Julie volunteered to do some reading on the topic and report to the class.

The next day Julie was most enthusiastic about a book which gave the probable geographic origins of plants and used it as a basis for her report. The science teacher recognized Julie's enthusiasm and suggested that she make a map of the world on which she could paste pictures of garden plants in the countries of their respective origins.

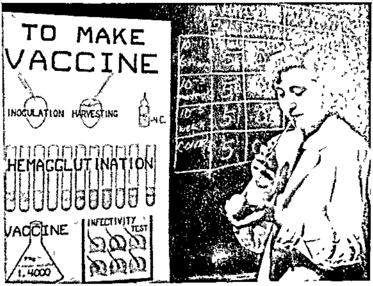
A teacher may select a pupil to do independent work basing his selection on the pupil's demonstrated abilities and interests. The pupil is usually pleased at being thus singled out and he may be attracted by the thoughts of substituting one form of work for another. He may also be stimulated by the prospects of entering his project in a science fair. Thus a pupil who normally would not think of deviating from regular class assignments is encouraged to follow up special interests.

Godfrey was a capable student but had far more enthusiasm for the physical sciences than for the biology course he needed for a science sequence. The biology teacher recognized Godfrey's problem and was sympathetic with him.

"Godfrey," he said one day, sitting down beside him, "I've just found this plan for a reaction timer. It measures the time a person needs after seeing a red light before he can put on the brakes. Do you think you could make it?"

A permissive atmosphere in the classroom helps encourage pupils to suggest their own problems.

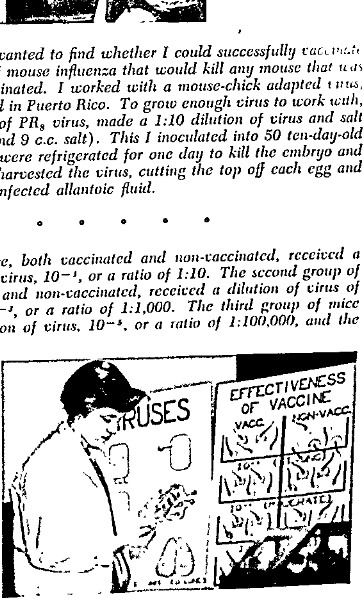
[2] It might be noted here that no science program is complete; it can only sample the most important topics. The most difficult decision in planning a program is deciding which topics to sample and where gaps must be left because of time limitations.



For my experiment, I wanted to find whether I could successfully vaccinate mice against a strain of mouse influenza that would kill any mouse that was not immunized or vaccinated. I worked with a mouse-chick adapted virus, PR_8, which was isolated in Puerto Rico. To grow enough virus to work with, I took a stock culture of PR_8 virus, made a 1:10 dilution of virus and salt solution (1 c.c. virus and 9 c.c. salt). This I inoculated into 50 ten-day-old chick embryos. These were refrigerated for one day to kill the embryo and chill its fluids. I then harvested the virus, cutting the top off each egg and drawing off the virus-infected allantoic fluid.

• • • • • •

My first group of mice, both vaccinated and non-vaccinated, received a very strong dilution of virus, 10^{-1}, or a ratio of 1:10. The second group of mice, both vaccinated and non-vaccinated, received a dilution of virus of moderate strength, 10^{-3}, or a ratio of 1:1,000. The third group of mice received a weak solution of virus, 10^{-5}, or a ratio of 1:100,000, and the fourth group of mice received no virus.... My chart shows the results after the mice had had the virus five days: blue mice with their tails up represent live mice; brown mice with their tails down are dead.



Mr. Thompson makes many of his assignments in the following manner: "For tomorrow I want you to do any one of the jobs listed on this sheet. If you can think of something else you would rather work on see me and we will talk it over."

A teacher must make an early decision about the amount of class time that a pupil may use for his special work. Usually it is well for all pupils to participate in field work and laboratory activities, and to view the same films and demonstrations. A pupil should be able to get started on his task during the remaining portions of several successive periods. If his interest is high enough he will put in much additional work outside of class. There will be exceptions; unusually talented pupils working on projects of high caliber may be given more time; pupils with unfavorable home conditions may need additional time to make adequate progress.

A teacher must also decide which requirements will be relaxed to permit independent work. Pupils of high intellectual capacity usually pass the same tests as their classmates without difficulty. There is little value in their engaging in activities which are designed to reinforce learnings; work on practice exercises and written reports can well be excused. For grading purposes, substitutions may be made; a report of a project may be used in place of one or more experiment reports and a grade may be given for the tangible accomplishments of the project in place of grades for regular assignments.

Comparable decisions in the case of the pupil who does not do so well on tests and other academic requirements are more difficult to make. The teacher may determine which segments of the planned material are of vital importance to the pupil and set these as minimum requirements that must be met; above this minimum the pupil may substitute his project work for activities required of the others. Or the teacher may decide that the outcomes of the independent work are of equal value to those resulting from the planned program and permit complete substitution.

PROVIDING FOR EXCEPTIONAL PUPILS IN HETEROGENEOUS GROUPS

Among the pupils in any one school there are certain to be a few who deviate widely from the norm in one or more respects. Some may be *academically* brilliant. Some may be seriously retarded readers. Some may be social rejects. Some may be serious disciplinary problems.

With normal distribution the teacher rarely encounters over one or two such exceptional pupils in any one class. The problem of pro-

viding for them is not troublesome if classroom procedures are flexible and the teacher is alert to his opportunities.

The brilliant pupil in the heterogeneous group. Special pains must be taken to make sure that the brilliant pupil is not ignored. It is far too easy to hold him to the same assignments and to the same standards as his classmates, assuming that because he attains high grades nothing more need be done for him.

It is a mistake to believe that brilliant pupils must be held back by being in the company of less gifted pupils. Pupils are held back, not by their classmates, but by stereotyped and inflexible classroom procedures.

The program for the brilliant pupil should be a judicious blend of regular class work and special assignments. He should work with his classmates on the introductory phases of each unit, he should participate in all field work, and in much of the group work. But while other pupils are doing *individual* work—reading, reviewing and writing—he should be engaged in activities that are suited to his superior abilities.

Usually the brilliant pupil is easily encouraged to do special work. He is curious; he grasps problems readily; he has a superior background. During regular classwork, as questions arise, he may be assigned the task of investigating some of these. Other pupils will undertake special problems also but his will be more complex. The brilliant pupil may be detached with one or two others for special group work. His partners need not be of equal caliber; each can make contributions.

The greatest help that may be given the brilliant pupil is the opportunity to do original research. He usually cares little for stereotyped exercises; he prefers to investigate problems that have unfamiliar outcomes. His research may begin as an outgrowth of regular classwork but he should be encouraged to continue it both in and out of school. Many of these pupils will willingly work evening after evening if the teacher will stay with them and give a little help.

The brilliant pupil can also be given special responsibilities in the classroom. He may prepare and present demonstrations. He may help supervise certain types of laboratory work. If he has leadership ability, he may take charge of groups working on special projects such as assembly programs. Working with other capable youngsters, he may keep laboratory equipment in order and take charge of the classroom library. These opportunities will help him develop broadly as well as specifically.

Retarded readers in heterogeneous groups. Seriously retarded readers who do not suffer from a lack of mental ability benefit from all phases

of the science program except those that directly involve reading or are based upon a background provided by reading. These pupils profit almost as much as their fellows when working with materials and when using audio-visual aids. They are handicapped chiefly by a reduced experience background and a feeling of inferiority in academic matters.

These pupils find meaningful a science program based chiefly upon direct experiences, such as field work, and supplemented by such audio-visual aids as films, slides and pictures. To profit fully, these pupils must feel that what they are doing is worthwhile and that they have important abilities. They need the confidence that comes with success.

Individual and small group activities provide many opportunities for retarded readers to excel. They can set up electric circuits, make models, perform experiments, put on demonstrations, and prepare visual aids. In addition, they may display leadership ability, artistic talents, and dexterity with tools to a degree that makes them outstanding among their fellows.

Retarded readers need not be denied opportunities to read. They must be expected to undertake reading assignments along with their classmates. However, assignments should be flexible to allow these handicapped pupils to find the required information in books suited to their degree of skill. When textbook assignments are made, retarded readers may be given study guides to help them locate specific items of information.

Few retarded readers are able to write well and most of them dislike writing. These pupils may be permitted to substitute diagrams, drawings and clippings for written assignments with the understanding that labels and captions are to be carefully prepared. They may maintain science notebooks on the same basis.

The retarded reader can be helped to keep up with his classmates in nearly all respects except in passing pencil-and-paper tests. Here he is at a distinct disadvantage. He has difficulty interpreting questions and writing answers. In addition, much of the material tested by this means is derived from reading. Though he is better able to handle short-answer tests than essay and completion tests, it would not be fair to his classmates to use such tests exclusively. This is one of the situations in which the retarded reader must recognize and accept his limitations.

Providing for the dullard. The term "dullard" is reserved here for the pupil who is truly lacking in native ability. There are fewer dullards in the usual teaching situation than might be supposed from hearing

teachers talk, because retarded readers and other handicapped pupils are often classed thus unjustly.

The true dullard is, as the name implies, "dull." [3] He has few strong interests. He makes few contributions to the work of the class. He is usually overage and therefore often oversized for his group; however he may be poorly developed and poorly coordinated. He makes few friends but he sometimes forms strong attachments for others. He is apt to be the butt of his classmates' jokes. He may not take offense if he does not understand that he is being ridiculed, but if plagued sufficiently he may fly into a blind rage.

The dullard is rarely a discipline problem except when other pupils deliberately incite him to get him in trouble. Generally he responds well to praise and is eager to do whatever is asked of him. But he needs sympathy and understanding. There is no purpose in holding him to conventional standards; he can see the same demonstrations, watch the same films and listen to the same discussions as his classmates without gaining more than indistinct impressions and unconnected ideas.

However, he is still a human being. He has intelligence and can learn facts about familiar situations and he can develop certain skills. He lacks mostly the ability to transfer learnings from one situation to another. As much as possible his work should be directed towards achievements that will help him in everyday living—safety habits, the wise use of household devices, care of plants and animals.

The dullard should be expected to do work along with his classmates but the nature of his assignments may be changed. He can do manipulative work but he will need help in organizing it. The problems with which he is faced should be one-step problems carefully chosen for their simplicity. Oral directions are needed because he cannot interpret written materials.

During a study of plant reproduction, Mrs. Clay asked Tom, a true dullard, to make a chart of different kinds of fruit. She provided him with seed catalogs, scissors, paste and a sheet of card. She helped him print a title. She asked him to cut out pictures of things he knew had seeds inside. Tom worked diligently on his project, not only in class but during a study period. The final chart was colorful and appropriate to the subject being studied.

[3] The dullard cannot be distinguished by IQ alone, although some people try to make this simple distinction. He is identified by a number of characteristics discussed above. It should be noted too that some pupils with low IQ's are not dullards, but secure low IQ scores because of emotional or other problems.

The dullard is happy to accept certain kinds of classroom responsibilities; he can water plants, clean animal cages, erase blackboards, and wash glassware. He attends these duties faithfully, often arriving at school early and leaving late.

THE SCIENCE PROGRAM FOR HOMOGENEOUS GROUPING

Schools that practice "homogeneous grouping" bring together in each section pupils with approximately the same academic ability as measured by intelligence scores and school success. For the median sections the science teacher has no special problems but for the extremes he is faced with real challenges.

Science for high-level sections. In the top one or two sections are concentrated the best students in a school. If there are any geniuses these will be included. Most of the pupils, however, will be in the "superior" category. There may even be some of little more than average ability but who have sufficient drive to rate well academically. In other words, despite the term "homogeneous" the top sections may show a considerable range.

These sections can be a pleasure to work with. The pupils have adjusted well to secondary school conditions. They all read well and have satisfactory mathematical skills and insight. They usually have rich experience backgrounds. Their interests tend to be academic in nature.

On the other hand, many teachers who ask for an assignment to these sections fail completely to provide a suitable program. They make one of two mistakes. Either they try to speed up the rate of instruction—covering more ground in the time allotted, or they provide more of the same program used for other pupils—more readings, more mathematical exercises, more written assignments.

The program for superior students should be planned with the over-all development of these young people in mind. They do not benefit by being crammed with more information and by perfecting minor skills. They need opportunities to explore their abilities and interests, to discover the satisfaction of research, and to become leaders of people.

A program for superior students makes extensive use of laboratory experiences. The mere fact that they can read well should not diminish the emphasis upon situations in which pupils must think for themselves. Time for additional laboratory work can be taken from that allotted for the review and drill activities provided for less able students. The

laboratory work should be largely of the research type; superior students do not need as much practice with laboratory skills as other pupils and they find little challenge in exercises the results of which are known beforehand.

Superior students benefit greatly from field experiences. They can comprehend industrial processes, research laboratory activities, and ecological relationships and they have the ability to do the follow-up reading necessary.

Superior students should not be denied opportunities to work with tools and other materials. These media are as essential for their education as for that of the less gifted. Indeed, superior students can surpass other pupils in such work because they can depend upon their reading for new techniques and processes.

Films and other visual aids have an important place in their program but these must be chosen with the nature of the pupils in mind. Many visual aids now on the market would be no more than a waste of their time. The best materials will awaken new interests, define problems, and aid in the solution of problems appropriate for the achievement level of the pupils.

The program for superior students may be highly individualized with pupils spending much time on special research projects. These projects should not be primarily reading projects but should deal chiefly with laboratory and field problems.

These pupils are capable of participation in the planning process. Some teachers do little more than outline the basic program at the beginning of the year. The pupils are brought into all unit planning and determine much of what is undertaken each day. Under these teachers the science classes bear more than a superficial resemblance to a science club.

Science for low-level sections. In these sections are grouped all the truly unfortunate youngsters in a school—unfortunate in their endowments and unfortunate in having to be in these sections. There may be a few dullards. There will be pupils lacking in academic skills. There will be pupils handicapped by underprivileged backgrounds. There may be pupils held back by physical illness or personality deviations or pupils who are emotionally unstable because of family strife. Some may be incorrigible delinquents. The pupils range greatly in age; sometimes seventh grade pupils are eighteen years old. Physically many of them are men and women. With a sprinkling of younger pupils in each section some peculiar problems arise.

Pupils in a low level section benefit little from a standard program that is merely diluted "down to their level." They need a program that

is planned specifically in terms of their maturity level, their lack of academic skills, their approaching entry into the adult world, and their feelings of inadequacy.

The school administration should feel responsible for providing the facilities needed for suitable instruction for these unfortunate youngsters. Classes must be kept small; the activities best suited to them, including construction, simple experiments, and other manipulative activities, are difficult to supervise. The classroom for these sections should be well stocked with tools, raw materials, simple science equipment, and art supplies. There must be ample workspace on tables and work benches. The library for this classroom needs a wide variety of books—not childish books, but books that are profusely illustrated and simply written.

The subject matter of the program should deal largely with concrete things with which the pupils are acquainted. They benefit little from the study of abstractions. They should learn about the repair of electrical equipment, the operation of automobiles and the wise choice of clothes rather than about the principles of heat transmission and cell division.

Visual aids that concentrate on practical applications are desirable. Those that deal with generalizations may mean little. Though the visual aids may be simple in their presentations they must not be childish lest they antagonize young people who consider themselves adults.

Pupils in low level sections benefit greatly from project work. They can make models, dioramas, and charts. They need opportunities to display these and receive recognition for their efforts. The subjects for these projects should be practical problems rather than attempts to illustrate scientific principles.

By keeping notebooks these pupils can gain some experience in writing. Most of the material, however, should be in the form of drawings, pictures, and clippings, all suitably labeled and supplemented with brief captions. For written material that the teacher considers important a technique may be borrowed from the early grades. The pupils talk over what is to be said and dictate it to the teacher who writes it on the chalkboard. The pupils then copy it in their notebooks. Thus it becomes their written work but they are not penalized by inadequacies of spelling and rules of punctuation.

Book research should be limited to the search for specifics such as the names of foods containing Vitamin C and the names of plants that live well in north-facing windows. The pupils may look for recipes, for lists of materials needed for projects, and for directions for building things.

They need special help for any reading assignments. Usually guide sheets telling them exactly what to look for and often telling them where to find the information are most useful.

Tests, of course, should involve a minimum of reading and writing. Performance and identification tests should be used whenever possible. Matching tests and multiple-choice tests, with plenty of practice, may be used for measuring understandings that can be verbalized.

SETTING UP SPECIAL PROGRAMS FOR PUPILS TALENTED IN SCIENCE

If maximum help is to be given to pupils with high scientific aptitudes, a special program must be provided. The program used for high level sections under homogeneous grouping is not sufficient because in these sections are many pupils with little interest in science as a career or even as an avocation. The special program can be much narrower and far more intensive.

The values of the special programs have been amply demonstrated in several schools as was discussed in chapter four. The caliber of instruction can be kept high; pupils can be challenged with high level problems; the teacher can spend more time on positive guidance and less on awakening interests and reinforcing learnings; and the pupils tend to stimulate each other.

Certain administrative problems are involved, however. The special sections must be kept small if adequate supervision is to be provided. This means that additional room space and teacher time must be found, not an easy task in some crowded and overloaded systems. It also means complexity in scheduling, especially if the pupils are not to be kept together for other classes. These problems are not enough to outweigh the values of special science programs but they must be taken into consideration.

Identifying the gifted in science. Truly gifted students are marked by more than the ability to attain good grades in a standard program. Many pupils without special talent attain good grades through hard work and perseverance. The truly gifted have a number of other characteristics that must be looked for.

Various standardized testing devices may be used. Intelligence test scores give a clue as to general intelligence; gifted students are generally considered to make up the top 20% of the population and will have IQ's above 120. Verbal comprehension tests tell how well a pupil can read; gifted students are generally excellent readers. Abstract reasoning tests indicate the power to interpret diagrams; tests of mechani-

cal relationships and of spatial visualization deal with other important characteristics.

No single one of the above tests is designed to isolate pupils with high talent in science, but taken as a whole they suggest capacity for science. They may be supplemented by special science aptitude tests. The important thing to remember is that no one test may be depended upon.

Subjective evaluation will also play a part in the detection of the talented in science. The following characteristics have been suggested for guiding observations:

1. *Extraordinary memory.* A boy who in the senior high year of high school could give at sight the square of any number between 1 and 100, or the senior girl who could repeat extensive information concerning the planet Jupiter based on her studies in the ninth grade are examples of students with extraordinary memories.

2. *Intellectual curiosity.* This trait is often indicated by a persistence in asking questions and an eagerness to investigate marginal content, which usually challenges only those who are intellectually mature.

3. *Ability to do abstract reasoning.* This may be revealed by unusual insight into probable discrepancies and by skill in formulating hypotheses from new data.

4. *Ability to apply knowledge to other situations.* A student who selects formulas and principles appropriate to a new situation and evaluates the results is exhibiting such ability.

5. *Persistence in worthwhile behavior.* This characteristic is common to leaders in science. It is reported that Edison worked continuously for 72 hours while working on the wax record. After he was 80 years of age he began the study of botany. He tested thousands of plants for rubber in the remaining 4 years of his life. A scientist does not give up easily. This type of perseverance should not be confused with aimless plodding.

6. *Insight into abstractions.* Insight is found to an extraordinary extent in the scientist and mathematician. Many teachers have had in their classes students who always seem to see the answer before the problem was completely stated. A student in geometry was asked to describe the figure formed by joining consecutively the midpoints of the sides of a quadrilateral. He gave the correct answer in a few seconds and immediately asked what figure would be formed by joining the midpoints of the sides of any polygon. Such insight is rare.[4]

Selecting pupils for the special program. Before any selection can be made, the numbers to be admitted to the program must be deter-

[4] *Education for the Talented in Mathematics and Science,* U. S. Department of Health, Education and Welfare, Bulletin No. 15, 1952.

mined. Too many pupils make supervision difficult; too few may make a program impractical from an administrative point of view. The ideal number for one person to handle is about twelve. A few more or less make no special hardships. Too few can be disadvantageous in developing an *esprit de corps* and in providing the stimulation that comes from within the group. It is better to accept some who are not of the highest capacity if they will work well with the others.

Because the final selection will probably come from among the honor students, records of grades make a good point of departure. The intelligence test scores and reading test scores of these honor students may then be checked for indications of high general intelligence. On the basis of these three characteristics—grades, particularly in mathematics and science, IQ's, and reading levels—a reasonable sized group may be chosen for further analysis.

Not all of the pupils thus selected will care to enter a special program in mathematics and science. The labor of investigation can be reduced by asking an expression of interest at this time, usually after a personal interview and with time for conferring with parents. However, if the effects of disappointing a large number of pupils is feared, this step may be deferred until later.

The final selection should be made on the basis of specialized tests, conferences with other teachers who know the pupils, and personal interviews.

In large systems there may be enough pupils of extremely high ability to fill a special section. In smaller systems there may be no more than one or two pupils of such high caliber. This should not be a deterrent to setting up a special section—pupils of moderately high ability benefit from the experience of working up to capacity. John Burdick of the Jamesville-Dewitt High School (Dewitt, New York) describes the first special section he set up in 1956:

> Selection of students was made on the basis of their demonstrated ability, their tested mental ability, and the judgment of previous teachers. We finally obtained a class of 14, not counting a Spanish boy who was an American Field Service exchange student. Twelve of these students fall into the "smart" student category, none into the "really bright" class. One girl was allowed to enter for reasons best classed as therapeutic, and one boy was allowed to enter in the hope that work at a more difficult level might stimulate him to achieve at somewhere near his mental level. Mental ability scores ranged from 116 to 123. Previous school achievement ranged from extremely high to, in the case of the boy mentioned above, barely passing.[5]

[5] Personal communication from John Burdick, science teacher, Jamesville-Dewitt High School, Dewitt, N. Y., January 12, 1957.

Organizing course content. Commonly special sections deal with materials comparable to that which the pupils would normally study under the standard program. Thus in the year when pupils would usually elect biology, the content of the special program is biological in nature, but enriched and intensified.

For ninth grade pupils, earth science is sometimes substituted for general science. The reason for this is primarily psychological; talented pupils could gain as much by an enriched course in general science.

When the special program is operative for the senior year only, a special course that cuts across conventional boundaries may be provided. The content of the course set up by John Burdick, referred to above, was as follows:

First semester	*Second semester*
Logic	Astronomy
Number theory	Electronics
Statistics	Relativistic physics
Calculus	Nuclear physics
Analytic geometry	Advanced mechanics
Non-Euclidean geometry	Aeronautics

Courses for talented pupils should be organized to permit pupils to explore deeply. If too much is crowded into the program, the material will be only superficially covered, and the classes will be turned into "cram sessions."

Field and laboratory experiences should be utilized almost to the exclusion of other approaches because in these situations pupils find problems that demand the fullest exercise of their special abilities. Any pupils can memorize information presented by the teacher, by books, and by visual aids, but only unusual pupils can carry on what is the equivalent of true scientific research.

Students in the special program should carry on individual projects that involve original research in so far as possible. Many classes may be in the nature of seminars, in which pupils present their problems and criticize each other's conclusions. The research need not be original in so far as the field of science is concerned but should represent original thinking on the part of the pupils. Sometimes they may verify results others have obtained; sometimes they may apply previous findings to new situations. The projects may involve the construction of apparatus which, though modeled after existing apparatus, will include original features to fit special needs or situations.

Suggested activities

1. For a unit in biology plan a list of activities that may be carried out by pupils working in small groups. These activities should provide for a wide range of interests and abilities.
2. Plan a unit in physics for a group of gifted pupils. Provide opportunity for the pupils to explore this unit in depth.
3. Plan a general science unit for a small class of retarded pupils. Provide opportunities for individual and group work suitable to these individuals.

Suggested readings

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ENCOURAGING READING THROUGH SCIENCE

chapter 18

Reading has become more important in the science program than ever before. No teacher today can be a master of the whole of the science field. He must depend upon books to supplement his program. He must refer pupils to books whenever they wish to investigate special topics with some depth.

As the need for reading has increased, the problems of using books have multiplied. Not long ago, boys and girls gained a major portion of their education through firsthand experiences outside the school. If a pupil picked up a book and read about fermentation or mechanical advantage or sheet erosion, he already had experiences with breadmaking or wheelbarrows or rain-washed fields to give the printed words meaning. Today, relatively few boys and girls have the basic experiences that once were taken for granted.

In addition pupils in the secondary schools have a much greater range of reading abilities now than formerly. At one time the retarded reader received little time or sympathy; he left school at an early stage. Today, a teacher may find in one class pupils of superior reading ability and pupils who, for all educational purposes, may be classed as nonreaders. This diversification intensifies the problems of using reading materials.

On the positive side, both the quality and the quantity of science books for young people have increased greatly. There was a time when the science textbook had to be relied upon for most of the reading that could be done in the science program. Today, libraries contain hun-

dreds of attractive, well-written and informative books that fit almost any interest and any degree of reading skill.

THE CHARACTERISTICS OF SCIENCE READING MATERIALS AND THEIR READERS

Reading provides experiences, which, though vicarious in nature, can be truly educational to pupils equipped with adequate skills and in possession of a sufficient experience background to make the words meaningful.

But it must be remembered that books and other reading materials have severe limitations in their usefulness. Printed words and punctuation marks are symbols that are intrinsically meaningless. Before they can serve their function pupils must be able to interpret them.

Functions of reading materials in the science program. Reading materials can be made to serve the following functions in the science program:

1. Description
2. Explanation
3. Recall of past experiences
4. Summary and organization
5. Suggestions and inspiration for new experiences
6. Problem setting
7. Persuasion
8. Developing an appreciation for scientific achievements
9. Developing an understanding of the scientific method
10. Developing a scientific attitude

Reading materials vary in their fitness for filling the above functions. Textbooks and encyclopedias, because of their concise writing, are excellently adapted for summary and overview, but they are not well suited for adequate descriptions; even their explanations tend to be too terse for proper understandings because they cannot deal with exceptions and uncertainties at sufficient length.

The best descriptions and the most adequate explanations for young people will be found in specialized books written for this age level, in pamphlets published by industries as an educational service, and in articles printed in semi-professional journals such as *Natural History*. The latter two sources are usually well illustrated.

Home experiment books give excellent suggestions for new experiences of the laboratory type. Special departments in popularized science magazines are also helpful. Suggestions for field experiences, however, must usually be gained indirectly from books and magazines describing things to do out of doors.

Biographical sketches of scientists point out the importance of the achievements of these men, the methods they used in solving their problems, and attitudes that governed their actions. Thus biographies help give an understanding of the ways of scientific research. The best of the sketches appear in popular magazines and in pamphlets published by industries. Longer accounts are found in book-length biographies.

A negative approach to the development of scientific attitude can be found in books and magazine articles that call attention to spurious claims of advertisers, self-styled "healers," and the like. Teachers may also use the same approach in a classroom analysis of advertising materials and other claims.

In addition to the biographical sketches referred to above, other articles in popular magazines describe the achievements of science and point out the importance of those described. Some of these articles are so well written that they should be added to a teacher's file of resource materials.

The limitation of reading materials. The most serious limitations of books and other printed materials are the limitations of words in general. Words are symbols; they have no meaning in themselves. They must be given meanings by their users. Both the writer and the reader must have had comparable experiences if they are to attach the same meaning to words. The less similar their backgrounds, the less exact will be communication between the two. This problem is probably more acute in science than in most other fields.

Additional problems arise when formulas, equations, graphs and cross-sectional diagrams are incorporated into the reading material. Many a pupil who can interpret common words is helpless when faced with such an expression as $.65 \times 10^{-6}$. *The fault is not his; he has not* been prepared for this type of reading.

The skill of the writer is an important factor; many failures to communicate must be attributed to the writer rather than the reader. If he includes too many thoughts in one sentence, if he does not punctuate carefully, or if he uses clumsy sentence construction, he will confuse many of his readers. If he allows just one extraneous thought to creep into a sentence, he may cloud its meaning; for want of a clear sentence, the meaning of a paragraph may be lost. The teacher with a strong background is able to jump past omissions and crude sentence construction without losing the context, but he cannot expect the same of pupils who are striving to interpret completely new material.

Even minor faults may confuse or discourage young readers. Type size that is too large or too small is known to represent a handicap.

Pages containing large masses of unbroken type, pages that are cluttered, pages with long lines of print—all interfere with effective reading.

The limitations of readers. Just as there are no perfect reading materials so there are no perfect readers. All pupils come into the secondary school with reading skills imperfectly developed. All need opportunities for extensive practice. The "reading problem" extends to superior readers as well as to retarded readers; none should be denied opportunities to improve their skills.

Chapter two describes the range of reading abilities to be expected in unselected groups of secondary school pupils. Most of the pupils cluster about a norm, half above and half below; a few spread out at the extremes. This is the normal distribution curve.

The nature of the norm must be understood. It is an artificial standard determined by administering arbitrarily selected samples of reading material to a fairly large number of youngsters. The norm does not represent an ideal attainment. It should not be considered a standard for success. It is not stable; over the years, if the general reading of pupils should rise, the norm will rise correspondingly, leaving an equal percentage below the norm. All that can be determined by the norm is the identity of pupils who read more skillfully or less skillfully than the bulk of their fellows. "Retarded" readers are inevitable and must be planned for, not condemned.

BUILDING READING INTO THE SCIENCE PROGRAM

Books and other reading materials are specialized teaching devices; they cannot be taken for granted. Deliberate planning is needed to utilize fully the maximum potentialities of each type.

Reading as a primary source of information. There are areas of science for which reading materials provide the only practical sources of information in the secondary school. Though the suitability of these areas for this level may sometimes be challenged, there may be good reasons for including them in the program. The dependence upon reading materials must then be recognized and planned for.

The topic for study was the nature of the solar system. Mr. Hanson wrote a list of questions on the blackboard and asked his pupils to find the answers in encyclopedias, supplementary textbooks, and other books in the classroom library.

This technique of providing pupils with specific questions is helpful for those individuals who cannot separate essential information from unessential information as they read. Another technique similar to the

above breaks the class into groups, each of which has a different assignment.

Miss Helmer divided her class into twelve groups and asked each to choose one of the members of the solar system for special study. The class then adjourned to the school library for the remainder of the period. The next day the groups reported on their findings. Many had done outside reading at home and in the community library.

Reading to follow up direct experiences. This is one of the most satisfactory uses for reading materials. The pupils encounter real problems and are motivated to read. They have gained a background that makes their reading meaningful.

A chemistry class had visited an agricultural supply center to become acquainted with the large number of organic and chemical fertilizers for sale there. The information on the labels raised many questions about the origin of the fertilizers, the chemistry of their action, and the influence each had on plant growth. Back in the classroom the pupils were referred to agricultural bulletins and textbooks, to advertising pamphlets, and to home gardening manuals which were provided for them.

Firsthand experiences may be planned deliberately to make use of publications that are available. This technique does not change the supplementary role of the reading material in the learning process.

Miss Baldwin had in her resource files twenty copies of a nature study bulletin on spiders. Before giving out the bulletins she took her class out to look for "funnel-web" spiders on the school lawn. The pupils, working in pairs, located the different portions of the webs. Back in the classroom, after the pupils raised many questions about the function of these parts, Miss Baldwin referred them to the bulletins for answers.

Readings may be used to give information about experiences pupils have had at an earlier time. This technique may not be completely satisfactory unless all pupils have had these experiences and have been impressed by them. There will almost always be need for some preliminary review.

Nearby Lake Goodwin, the only sizable body of water for miles around, was a popular recreation area. Mr. Larssen planned a ninth grade science lesson on its formation. He opened the lesson with a discussion about the characteristics of the lake: its general shape, length, width, deep and shallow areas —information that could be gained by boating, swimming and fishing. This information was summed up on a map which Mr. Larssen sketched on the blackboard.

Mr. Larssen then termed the lake an "oxbow" lake and suggested that the pupils read about these lakes in the books he had provided, trying as they read to account for the origin of Lake Goodwin.

Reading to follow-up discussion. Out of the discussion of interesting topics, questions inevitably arise. Many of these questions are best answered by suitable readings.

A popular high school couple were overcome by exhaust fumes in a parked car but were revived through prompt action of the police. Mrs. Dunning mentioned the event in her biology classes the following day. Pupils immediately began raising questions about the effects of carbon monoxide, the time needed for recovery, and the like. Mrs. Dunning helped the pupils clarify their questions, organize themselves into groups, and use various available references to find answers.

Reading to set problems. Out of certain types of reading arise questions which lead to other activities—experimentation, field observations, and the like.

A science bulletin to which the science classes subscribed printed an article on tent caterpillars. Pupils were able to recognize these insects but knew little about life histories and specific habits. They found the article interesting and wanted to take a field trip to look for some of the characteristics described.

Controversial material is useful in setting problems. Out of the arguments arise questions that pupils want to solve.

George reviewed a book on Mars for his class, using an opaque projector to show some of the illustrations. One view gave an artist's conception of a Martian landscape with its "canals." The teacher asked how wide a canal would need to be to be visible from the earth. The resulting controversy touched off many other issues, and the pupils became eager to know how astronomers arrive at the facts and figures so commonly published.

Reading to suggest activities. Reference has already been made to the many excellent books of experiments and science projects that have been written for young people. (See appendix for a listing of such books.) There are several techniques for using these books.

Pupils may be assigned certain tasks which require the use of these books. Teams of pupils may be asked to look up directions for carrying out specified experiments or demonstrations. Or the pupils may be given freedom to look for activities of their own choice.

During a unit on electrochemistry, the class was divided into groups of three each. The groups were asked to look in the various books listed on the

assignment sheet for demonstrations of electrolytic processes that could be presented to the class. The following day the groups selected the demonstrations they would like to present and began necessary preparations.

Pupils may be encouraged to find suggestions for activities that are not closely associated with regular class work. They may present their results during time regularly set aside for special reports.

Each Tuesday, the eighth grade science teacher provided time for special reports. One day two boys demonstrated a model reaction turbine. The teacher asked the boys to tell where they found the directions for the demonstration. The boys showed the book to the class and gave a brief review of its contents.

The teacher may put a book of activity suggestions in the hands of a pupil who seems in need of special challenge.

Josephine's biology teacher suggested that she might be interested in a bulletin put out by a natural history museum. Josephine was fascinated by the suggestions for preparing dioramas. She chose to make a diorama of seashore life, a project that became almost a family affair after she persuaded her parents to take her to the coast for specimens and to museums for ideas.

Using books to answer irrelevant questions. A teacher often hears questions which seem too important to be ignored but which if recognized properly would divert seriously the line of thinking of the class. Sometimes he can refer the questioners to suitable books.

During a discussion that followed experiments with buoyancy in fresh and ocean water, one boy raised a question about the nature of the salt in ocean water and whether it was the same as the table salt used in the experiments. Not wishing to divert the attention from the subject of buoyancy, but realizing that this one pupil had a point that might be profitable if explored further, the teacher gave the pupil two specific references in which suitable information might be found.

The practice of referring pupils to books for answers to their questions can be abused. Whenever possible specific sources should be mentioned; otherwise the teacher should help the pupils find references at the first available opportunity. The pupils should also have opportunities to present their findings to the class as a form of recognition for their efforts.

Using books to provide for individual differences. Because reading is largely an individual activity, books and other reading materials enable pupils to follow up their own special interests and work at their own

rates. If these reading materials are appropriate for many different degrees of reading skills, all pupils may use them.

An assortment of books helps take up some of the slack that develops when pupils are working on uniform assignments. Inevitably some pupils finish ahead of others. Since these rapid workers are usually good readers they turn freely to books while their classmates are finishing their tasks.

In addition, a teacher finds time during periods of assigned reading for individual conferences. If the materials provided are interesting and the purposes for reading are clear, little supervision is needed.

TECHNIQUES FOR DIRECTING PUPILS TO READING MATERIALS

It is not enough just to have reading materials available. Many pupils do not turn freely to books. All pupils need help and encouragement in using reading materials wisely.

Preparing uniform reading assignments. Uniform reading assignments are desirable when a book or pamphlet contains a block of information that is so well presented that each pupil should have contact with it. It is unfortunate that so many teachers apply no such criteria to the subjects of their assignments. Their indiscriminate use of uniform assignments wastes much pupil time and energy and dulls their enthusiasm for science.

Uniform assignments are most commonly made for readings in textbooks but they may be made for readings in supplementary materials as well. Sometimes teachers have bulletins and pamphlets in sufficient quantities for class use. There are also ways to make assignments so that all pupils are able to read the same passages in one copy of a book.

Miss Williamson planned a short biology unit on human inheritance. She prepared an assignment sheet that included among the required activities several readings in books that she provided. The books were all single copies and Miss Williamson explained as she gave out the sheets that they should use the books whenever they were available. She asked for volunteers to begin reading the books immediately.

Using a variety of reading assignments. Sometimes a teacher may prepare a number of short problems and allow the pupils to select those they wish to work on. Usually more than enough topics should be listed so that the last pupils to choose have some choice.

If the problems are simple, perhaps no more than a single question

to be answered, pupils may report their findings orally while the listeners record the answers on their own question sheets.

Thirty-five species of insects were collected on a biology field trip. The teacher asked each pupil to select one insect and read about its eating habits and life pattern. As reports were made, the pupils entered the information in a table in their notebooks. Afterwards, several pupils volunteered to investigate the remaining species in order that the table be complete.

With more complicated problems it may be better to center each one about the preparation of a visual aid for which reading is necessary. Sometimes assignments to small groups rather than to individuals will prove more satisfactory.

During the study of sound each pupil in a physics class was asked to choose a musical instrument which he would explain to the class. Each was to consider the means by which the sound is produced and the pitch varied, and the factors affecting the quality of the sound. He could make use of demonstrations, charts, toy instruments and the actual instruments in making his presentation.

Voluntary assignments. A teacher may ask for volunteers to investigate certain subjects and report back to the class as a whole. These assignments may have been planned in advance or they may be a spontaneous outgrowth of situations that arise in class work. Such assignments should be based as much as possible on reading materials available to the pupils. It is discouraging to volunteer for an assignment only to discover that the needed information is not available.

The teacher may call for volunteers from the class as a whole or he may ask specific pupils if they would be willing to undertake the assignments. This last procedure is advisable if the only reading material is so advanced that high academic ability is needed to interpret it. Otherwise, some of the poorer readers may find themselves in frustrating situations.

Group reading assignments. Although reading is generally considered an individual activity, there are situations in which groups may profitably undertake special reading assignments. Sometimes a problem may be subdivided to give each pupil a special task. Sometimes pupils may bring together the results of their readings for comparison.

A group of physics students volunteered to compare what a number of textbooks, supplementary books and encyclopedias said about the nature of light. The pupils summarized the information for the class and presented the different viewpoints to point out the uncertainty existing in the minds of the authors.

The "reading specialist" in group work. In certain types of group work each member has special responsibilities. Commonly a person is needed to do book research.

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The personnel of each group consisted of a chairman, a recorder, a cartographer to prepare a map, and an artist to make diagrams. One pupil was to organize the final report and a librarian was chosen to be responsible for the field guides and for organizing the reading about the life histories of the birds seen.

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Using library facilities. An acquaintance with the books in the school library makes it possible for the teacher to make definite library assignments with confidence that pupils can find the material needed. It is common practice to send single pupils or small groups of not more than four to the library during class periods to do special book research. These pupils should have specific assignments and should have worked out exact procedures before being sent to the library. Otherwise they waste time and even become discipline problems.

When libraries have the facilities for class work, they welcome the presence of an entire class under the supervision of the teacher. Arrangements should be made in advance so that there are no conflicts with other groups. The pupils should know exactly what they are to do in the library and should have their order of procedures worked out in advance.

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access to them. The pupils themselves usually volunteer information about the books they have at home and the teacher may acquaint himself with the titles in the public library. Suggestions for research may then be given to specific pupils.

All completed assignments should be given special recognition through time for oral reports or through space for displays resulting from the book research. Such rewards encourage the pupils to continue with their outside readings and stimulate other pupils to undertake reading assignments for themselves.

Encouraging free reading in science. Science teachers should remember that science is apt to produce extremes of interest and that these differences will show up in reading achievements of their pupils. A highly interesting program has the effect of shifting the ability curve towards the high end, as pupils put additional effort into their reading. Conversely, if the program is dull and if reading materials are used unwisely, the effect is to shift the curve the other way.

Pupils may read for one or more of several reasons: because they have a problem they want to solve, because through reading they can escape into another world; because they want to please the teacher; because they wish to work with close friends; or because they want the prestige that knowledge gives. Teachers may make use of all of these motives in the science program.

STIMULATING PUPILS TO READ

Even the most avid readers need occasional encouragement to direct their efforts into more profitable fields. And reluctant readers must be confronted by carefully planned situations if they are to be challenged into using reading materials effectively.

Problem setting. Problem setting is used throughout the science program to stimulate activities of many kinds. It is the single most effective technique for encouraging reading.

Miss Carpenter asked her biology pupils to recall how they felt when alone in the dark and a bit frightened. They described some of their sensations—awareness of slight sounds, a tendency to jump at unexpected noises, rapidly beating heart, sweating, a feeling of panic. She then asked them to describe how they felt when very angry. The pupils mentioned the quickened heart rate, a feeling of strength and a tendency to rashness. One girl mentioned that she felt sick afterwards.

Miss Carpenter raised the question of the situations in which these reactions might be useful. She cited the example of a soldier scouting alone

in enemy-held territory who later would be engaged in hand-to-hand combat. The pupils discussed these and other situations.

Finally, Miss Carpenter raised the question of what happens to speed up heart action, increase awareness, and bring on the other reactions discussed. She suggested that the pupils read about the adrenal gland and its functions in the various books she provided for this purpose.

Pupils may also be encouraged to set up their own problems resulting from interest in mutual experiences in or outside the classroom.

An unusual fall thunderstorm killed one of two men who sought shelter under a tree. The ninth grade pupils immediately were curious about the reason for the death of only one man while his companion only a couple of feet away was unharmed. The science teacher explained that he did not know much about the action of lightning and suggested that the pupils make a list of questions that would likely be answered by looking in books and other references. While the pupils listed the questions, the teacher looked in his files for clippings and bulletins and borrowed several resource books from the library.

Individual pupils may sometimes be challenged by special problems.

During a demonstration of the mercury barometer, the seventh grade had its first experience with mercury. Mr. Hanson cautioned the pupils about getting mercury on rings or bracelets and showed them an inexpensive ring that had lost some of its plating by contact with mercury. One boy asked if the gold could have been recovered from the mercury. Mr. Hanson asked if any of the pupils had been to a former gold mining district in a different part of the state. Several pupils had been there. Mr. Hanson explained that mercury had been used in the recovery of gold at these mines and suggested that anyone interested might read and report the process that was used to recover the gold. The boy who raised the original question volunteered to look for the answer. Another who had visited one of the abandoned mines offered to work with him.

Utilizing interests in experiments and project work. Many pupils enjoy experiments and science projects. They turn readily to well illustrated and excellently written books describing things to do in science. A teacher need only display the books or mention them briefly to insure their use. The readers include pupils with many degrees of ability. The very poor readers may spend hours with these books, locating suitable activities and carrying them out. Or the same pupils may read the books without carrying out the activities. They seem content to perform the experiments in imagination while enjoying vicariously the excitement of experimentation.

Mr. Pack put a copy of a book describing projects with paper milk cartons in his classroom. For a month, one boy read the book during much of his spare time in school and even borrowed the book to take home for several nights. But during that time he did not undertake a single one of the projects in so far as Mr. Pack could determine.

Partnership reading projects. Adolescents like to work together and may often volunteer for reading projects when two or more can work at the same time.

A question was raised in Mrs. Latimer's eighth grade science class about the way the age of the earth has been estimated. Mrs. Latimer suggested that anyone interested might do some special reading to find out more about the subject. The next day two boys brought in a special report. One boy had a set of encyclopedias at home and had invited a close friend to spend the evening with him looking up the information.

The boys were probably motivated in large part by their desire to be together for the evening. However, this does not diminish the importance of their having spent some time reading. They might otherwise have devoted this time to less profitable activity.

Providing free time for reading. Some pupils will read if they are given class time but will rarely turn spontaneously to books outside school hours. Once having started on a book or pamphlet however, these same pupils may become sufficiently interested to finish the reading material on their own time. This is an important argument in favor of providing free class time for reading. This time may be provided for working on specific reading assignments or for working on one of a variety of assignments listed by the teacher. Reading time may also be provided for free choice from any available reading materials. Not all pupils need to be given reading time simultaneously. Pupils who complete other work in advance of the class may be given time until the others catch up. Some pupils may be given the privilege of reading while others carry out different activities.

Encouraging browsing. Fortunate is the teacher who has a classroom library made up of a rich assortment of books and pamphlets. These may be set out for pupils to look through whenever they have free time. In this situation, many pupils discover books that they would not otherwise encounter. Lacking a classroom library, the science teacher may borrow assortments of books from the school library for short periods. He may supplement these with free or inexpensive pamphlets obtained from industry and governmental agencies. Such materials for browsing need not necessarily be relevant to the material under consideration by the class.

Providing interesting associations for reading materials. Interest-capturing displays may be supplemented by pertinent reading matter in which pupils may find answers to questions that arise from the displays.

Mr. Cole displayed the empty shells of several kinds of turtles together with a terrarium containing a live wood tortoise. Beside the display he placed a well illustrated book on turtles. Later he found that all the pupils in his science classes had at least thumbed through the book and several had read it completely.

Providing samples of interesting reading materials. Elementary school teachers commonly use the technique of reading samples of books to their pupils to awaken interests in the books. Science teachers may employ the same technique.

Mrs. Bates read a section of Paul DeKruif's Microbe Hunters *aloud to her ninth grade science classes. In each class two or three girls asked if they could borrow the book.*

Voluntary book reports by the pupils. Well-presented book reports sometimes awaken interests in the books reviewed. Pupils usually need help in making the presentations interesting. They should be persuaded to give examples from the books rather than a superficial treatment and they should be encouraged to use visual materials whenever possible.

Two boys of Mr. Rice's general science class gave a review of a book presenting many interesting experiments in chemistry. During the presentation they performed one of the experiments described in the book.

Frequently pupils can find visual materials described in the books they read; these they may use to illustrate the points made by the books. Maps, blackboard diagrams, charts and large pictures are helpful.

Using science fiction. Charles C. Smith, a teacher of physics and chemistry, believes that science fiction has a place in the science program. He writes:

> Science fiction is generally thought of as a development in the present century, but actually it has a history extending far into the past. Anthologists list among its early examples: Plato's *Atlantis*, More's *Utopia*, and Bacon's *The New Atlantis*. They continue with such names as Swift, Defoe, Kepler, Poe, Verne, Bellamy, Wells, Buchan.
>
> Here is a great motivation force thrown right into our laps What are we going to do about it? Can we afford to ignore the responsibility of guiding our students through the good, bad, and indifferent grades

of science fiction that beckon to them from newsstands, radio, and television? Do we have the vision to see that if wisely selected we can use it for motivation and teaching? [1]

DEVELOPING SPECIAL READING SKILLS

Pupils constantly encounter in the science program new words, new formulas, and other unfamiliar symbols. They need help with these.

Learning new words. Whenever possible, new words should be associated directly with the things they represent. These words should not be given orally only; pupils must see what the words look like if they are to recognize them during their reading. Carefully printed labels attached to objects represent one of the best ways for insuring desirable associations. Pupils may set up these displays.

Two boys set up a display of electric motors for their classmates. One model had colored strings leading from its major components to labels on the bulletin board behind the display table. The other motor could be operated by pressing a switch. With the second motor was a list of questions about the motor, which, to be answered, required a knowledge of terms.

Good models and photographs, though not quite so effective, can be used in presenting new words when actual materials are not available. Diagrams should be depended upon only as a last resort and even then every effort should be made to help the pupils know what the diagrams represent. When used with real materials, however, diagrams are of great value.

Mrs. Richards gave her pupils the flowers of narcissus plants, razor blades and cross-sectional diagrams of the flowers. She asked the pupils to cut open the flowers and identify each of the labeled parts.

The more times an association is made, the greater the impact. Associations may well be made through several different approaches. If a word is considered essential, not only should there be several associations made during the presentation of the word but so also should there be reteaching to insure mastery.

A teacher may list words he expects pupils to encounter and ask the pupils to check on the definitions in dictionaries and glossaries. Better yet he may ask the pupils to skim through assigned reading and pick out doubtful words themselves. However, it should be remembered that dictionary definitions are but words and may be of no

[1] Smith, Charles C., "Science Fiction—Asset or Liability?" *The Science Teacher*, October, 1953.

more meaning to a youngster than the original word. There can be no substitute for associations with real things and conditions.

Many science words are composed of familiar prefixes, roots, and suffixes. During the presentation of one of these words the teacher *may help pupils analyze the word to arrive at its meaning.* For example, a teacher may write the word *micrometer* on the chalkboard and then divide it into two parts. He might ask the pupils to name as many words beginning with *micro-* as they can; they might list *microscope, microbe,* and *microwave.* The teacher would then call to their attention that all of these words are associated with something small. Next he would deal with *-meter* in the same way and the pupils would see that the word means "measure-small."

For practice with words some teachers use crossword puzzles and word games. Each additional experience of this kind adds to the mastery of words.

Teaching chemical formulas and other symbols. Physics and chemistry utilize symbols more than the other sciences. It may be that part of the difficulty of these courses is due to the introduction of symbols without sufficient preparation; certainly the basic concepts in these subjects are not difficult to grasp. Table 14 gives the results of a study of the use of mathematical terms in textbooks and illustrates why unprepared pupils have difficulty with physics. A similar survey of the use of formulas and equations would show why the same pupils would have difficulty with chemistry.

Textbook	*Average number of different difficult words per book*	*Average number of different difficult mathematical terms per book*	*Average percentage of different difficult words that are mathematical terms*
Physics	1407	159	11.3
Chemistry	1901	90	4.7
General science	2109	103	4.9
Biology	3019	81	2.6

TABLE 14. *Comparative frequency of occurrence of different words in selected textbooks in four high school subjects.* (Curtis, Francis D., "The Mathematical Vocabulary Used in Secondary School Textbooks of Science," *Journal of Educational Research*, October, 1944.)

Teachers are constantly devising new techniques for helping pupils grasp the significance of abstract symbols. Various types of flashcards are used for quick recall. Card games resembling the game of "authors" are used to review knowledge of groupings; a chemistry teacher has made one that uses the symbols for the chemical elements.

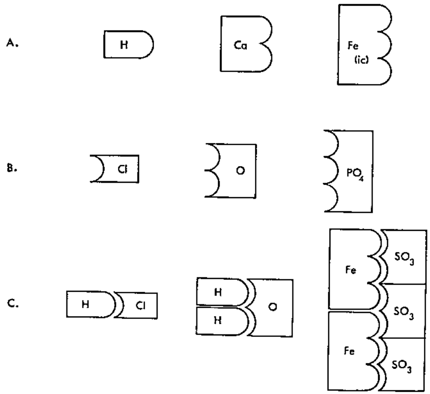


FIGURE 17. *A flannel board. Elements with a positive valence are prepared with semi-circular projections on the right side (A). Elements and radicals with negative valences are prepared by placing on the left side indentations that match the projections on the elements with positive valence (B). By combining the positive and negative elements and radicals (C), it is possible to show graphically why two atoms of hydrogen unite with one atom of oxygen, while only one atom of hydrogen is necessary to unite with one atom of chlorine, and why two atoms of iron will unite with three sulfate radicals.* (Lape, Richard H., "A Device for Teaching Formulas and Equations," *The Science Teacher*, March, 1952.)

Figure 17 shows a "flannel board" which one teacher uses to help pupils understand chemical formulas. The cut-outs are backed with sandpaper so that they will hold to the flannel-covered display board when pressed in place. As can be seen, cut-outs representing elements with positive valences have semicircular projections and cut-outs representing elements with negative valences have cusps. The cards may be put together to represent various compounds.[2]

Molecular structures are commonly illustrated with sticks, wire, balls of clay, and with wooden construction sets. Commercial models

[2] Lape, Richard H., "A Device for Teaching Formulas and Equations," *The Science Teacher*, March, 1952.

are also available. Atomic models are sometimes illustrated with variously colored thumbtacks representing electrons, protons, and neutrons, pressed into a tack board on which have been drawn concentric circles to represent electron rings.

To illustrate Mendelian formulas, teachers sometimes use "chicken rings"—linked plastic rings placed on the legs of fowl for identification purposes. They come in various colors and can be linked or unlinked as desired. Dyed pipe cleaners have been used similarly.

Help with diagrams. Most science reading materials include a large number of diagrams and drawings among their illustrations. Commonly these are an integral part of the discussion and any failure to interpret them correctly handicaps the reader seriously. Teachers must realize that the person who understands the material has no difficulty with the diagrams but that the person who is trying to grasp the context with no background to depend upon may see nothing in a diagram but lines and spaces. The problem of interpreting a diagram into a three-dimensional image is not simple. Teachers should begin early in the secondary school with carefully planned experiences with diagrams.

Mr. Axtell set up two sets of apparatus that were diagrammed in the textbook but he made no reference to them in class. The homework assignment for the next day included reading the section of the text which included the diagrams. The next day the pupils came to class very excited because they knew how to use the apparatus.

Pupils need many such experiences in associating diagrams with real things until interpretation becomes easy. Then pupils will no longer be so handicapped when they encounter materials that utilize diagrams extensively.

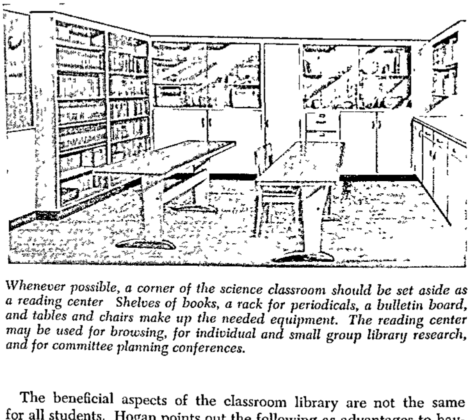
FACILITIES TO ENCOURAGE READING

It is customary to house most of the science books and other reading materials in the school library where they are available to the entire student body. Various plans for the use of these books are established. Sometimes books may be checked out for home use. Sometimes certain books are kept on reserve and can be used only in the library. In some schools a few pupils may be sent to the library for reference work; in others this is not permitted. In some schools a full class may be taken to the library for a special lesson; other libraries are too busy for this to be practical. No matter what the plan, there is always some problem in gaining immediate access to books that might amplify

class work. There is much to be said for having an adequate assortment of books within the classroom itself.

The classroom library. There are several ways to use the classroom library. The reference-book method of teaching is one of the commoner methods. Encyclopedias, several sets of supplementary textbooks, and associated reading materials are kept on hand for use when pupils are asked to investigate specific topics.

Some schools offer advanced courses in one or more of the sciences. These courses require more advanced literature for the classroom library. A few high schools are experimentally offering college freshman level courses in science, a procedure which allows the students to enter college with advanced standing. For this type of class work, the classroom library should contain more advanced reading materials.



Whenever possible, a corner of the science classroom should be set aside as a reading center Shelves of books, a rack for periodicals, a bulletin board, and tables and chairs make up the needed equipment. The reading center may be used for browsing, for individual and small group library research, and for committee planning conferences.

The beneficial aspects of the classroom library are not the same for all students. Hogan points out the following as advantages to having a science library: "The slow reader with a little instruction and guidance learns to seek out books on his own level. A classroom library also provides one of the least expensive and most flexible serv-

ices for talented children. The room library enables such gifted students to explore new fields as rapidly as their capacity permits."[3]

Classroom libraries, as reported by Walraven and Hall-Quest, undoubtedly have interested pupils who did not have the initiative to go to the main library on their own.[4] Many students will find, after being exposed to books, that reading is indeed a pleasurable and worthwhile experience.

Location. The science library should generally be located in a corner of the classroom. In the combination classroom-laboratory the library may be located either in the classroom or in the laboratory part of the room. An exception to this would be the combination chemistry classroom-laboratory, in which it would probably be more advisable to locate the library facilities some distance from the laboratory work area.

It is more advantageous to have a library in each science room rather than to have the facilities concentrated in one room. The former arrangement gives the students in the various classes greater access to the library facilities.

Furnishing a classroom library. Sizable and attractive bookshelves should be provided for the books. Open shelves invite readers to browse but closed shelves give more protection to the books. When planning the shelf space thought should be given to future space requirements.

Inclined shelving is especially advantageous for the display of magazines and pamphlets. Filing cabinets may be provided for the storage of pamphlets not on display.[5]

A special bulletin board for the library area can be used to display pertinent clippings, small pamphlets, circulars, and jackets of newly acquired books. A colorful bulletin board attracts pupils to the reading area.

The classroom library should have at least one table and seven or eight chairs. If there is table space for six or more pupils, the reading center can be used for committee work.

Selecting and procuring science reading materials. In 1951, Webb estimated that approximately two hundred new books concerning science at the high school level appeared annually. With the current emphasis on science, the number of books appearing in this field

[3] Hogan, Thomas F., "Our Classroom Has 200 Textbooks," *Scholastic Teacher,* May 17, 1956.
[4] Walraven, Margaret K. and Hall-Quest, Alfred L., *Library Guidance for Teachers,* New York, Wiley, 1941.
[5] Richardson, John S., "The Storage of Pamphlets and Charts," *School Science and Mathematics,* November, 1945.

increases yearly. Since it is impossible to purchase all of the new books as they appear, the science teacher must decide which ones to order with the budget available. Webb offers some suggestions to aid the teacher in selecting new books for the high school science library:

1. Select recent books, since, as Webb phrases it, "Old books may interest the collector of antiques, but not youth."
2. Regardless of the size of the order, select a diversified collection of books.
3. Select books with a wide range of reading levels. Webb states that this is necessary for two reasons. First, this provides for individual differences. Secondly, an average high school student may read lower level books for interest but college level books when seriously seeking information.
4. Books should be selected to meet the instincts of high school youth, e.g., hero-worship, heroic occupations, adventure, collecting instinct, etc.
5. Select some science books for vocational guidance.
6. Select some scientific reference books.
7. Select an occasional science book for its literary style.[6]

A copy of each of the best high school textbooks in the particular science field concerned should be included in the science library. If a reference book method of teaching is employed, several copies each of three or four different textbooks should be provided. In addition to the high school texts, a few carefully selected copies of college texts for the particular field should be included.

A general encyclopedia should be available in the central school library. One or more scientific encyclopedias may be kept in the main school library, unless the school has only one science room or can afford copies for each of the science rooms.

Each classroom library should have a good dictionary. Copies of appropriate scientific handbooks should also be kept in each of the classroom libraries. Other reference books concerning specific topics should be kept in the appropriate classroom science libraries.

Many of the books in the science library, of course, will be technical in nature for individual research purposes. It is well to have a wide range of subject matter areas represented. In addition, science books for recreational reading have an important place. Among these latter will be science fiction and popularized science books.

In the appendix are lists of books, pamphlets and magazines which would provide the nucleus of a good science library. A selected list of paperbound science books for an inexpensive library has been pub-

[6] Webb, Hanor A., "The High School Science Library," *The Science Teacher*, March, 1951.

lished by the American Association for the Advancement of Science.[7] As new books are released they are reviewed in various scientific journals. Science education journals such as *School Science and Mathematics* compile lists of books that have been published each year.

Suggested activities

1. Choose an eighth grade general science unit. List the books, periodicals, and pamphlets that you would like to have in the (a) classroom and (b) school library to supplement this unit. Assume that there is a wide range of reading abilities in the class.
2. Select a specific science book that you think every pupil should read in chemistry class. Plan a method to stimulate your pupils to read the book.
3. Set up a bulletin board display designed to interest pupils to do supplementary reading for a specific unit.
4. Assume that you are teaching a science class made up entirely of seriously retarded readers. Make up a bibliography for a specific science unit using books and other reading materials suitable for this group.

Suggested readings

Behnke, John A., "Traveling Science Libraries for Small High Schools," *Science*, July 29, 1955.

Carson, Thomas E., and Davies, Ruth Ann, "Teaching and the Library," *The School Review*, February, 1948.

Liston, Florence, and Woodsum, George, "An Inexpensive Scientific Library," *The Science Teacher*, October, 1955.

Otto, James H., and Ross, Mildred I., "Science Promotes a School Library," *Library Journal*, May 15, 1946.

Reading in the High School and College, Forty-seventh Yearbook of the National Society for the Study of Education, Part II, University of Chicago Press, Chicago, 1948.

Smith, Charles C., "Science Fiction—Asset or Liability?" *The Science Teacher*, October, 1953.

Webb, Hanor A., "The High School Science Library," *The Science Teacher*, March, 1951.

[7] Deason, Hilary J., *An Inexpensive Science Library*, American Association for the Advancement of Science, 1515 Massachusetts Ave. N.W., Washington 5, D. C., 1958.

IMPROVING COMMUNICATION SKILLS IN SCIENCE

chapter 19

Communication in science should be concise and objective. It is not an easy style to master. Professional writers spend hours on each short article they produce. Many prominent men employ specialists to prepare their speeches. And the articles of prominent scientists commonly require drastic editing before they can be published. Secondary school pupils are understandably lacking in skills with this type of self-expression. They have had little practice and little help.

The responsibility cannot be shifted to the English teachers. The English program has been allotted but a fraction of the time needed to produce accomplished writers and speakers. English teachers can do no more than lay the foundation upon which other teachers, including science teachers, can build.

Science teachers need not think of themselves as teachers of communication skills. They make their greatest contributions when they set up situations in which pupils actively desire to write or speak about their science experiences. In these situations pupils are stimulated to conscious efforts at self-improvement and they gain the practice that is so essential for increase in the powers of self-expression.

VOCABULARY DEVELOPMENT

Words are but symbols that have no meaning until the user is able to associate them with mental images and sensations. Vocabulary development consists of providing the proper associations, giving prac-

tice with these associations and reteaching after periods of forgetting.

Commonly vocabulary development includes provision for the experiences upon which associations are based. The person who has not seen cork may associate the word with the wrong substance or make no association whatever. This aspect of vocabulary development is of particular concern to the science teacher because so many words of science deal with things and conditions that pupils have never encountered previously.

To further complicate the process of vocabulary development there are, in effect, four different vocabularies that must be developed in parallel—a listening vocabulary, a speaking vocabulary, a reading vocabulary, and a writing vocabulary. These are not at all the same. The first two depend upon sound symbols, the last two upon visual symbols. There is a difference between hearing a sound and producing it. There is a difference between seeing a symbol and writing it. Hearing and seeing are passive; meanings are often suggested by context. Speaking and writing demand active recall and require a much higher level of previous learnings.

The vocabulary of science. All special fields have their technical terms. Science, with its many subdivisions, has developed the most extensive specialized vocabulary of them all. But scientific words are not science in themselves. They are tools with which specialists communicate with one another. All understandings about commonplace phenomena can be expressed in commonplace terms.

Some of the words of science are so useful as to be worth teaching. "Distillation" is one of these; it is much more concise than any equivalent in basic English and has many applications in post-school situations. "Photosynthesis" is debatable; it has a precise meaning that is rarely appreciated even by science teachers themselves, but it is a useful term in science courses. "Polydactylism" has little value in a nonspecialized science course and none outside of school situations; it does not justify inclusion in the required vocabularies of young people.

Scientific jargon, which is useful to specialists trying to be concise, has little place in the secondary school program. It may be confusing. The teacher who uses "hot" instead of "radioactive" may give a totally wrong impression for the sake of saving four syllables. Non-specialists are apt to use jargon because of its novelty rather than because a purpose is served.

Occasionally there is a difference between the scientific definition of a word and the common usage of the word. No better illustration exists than the word "steam." For centuries, steam has referred to the visible cloud above hot water. Physicists, however, upon learning

about evaporation redefined the word to apply to invisible water vapor, a definition accepted by dictionaries.

Science teachers are apt to insist that pupils abandon the common association and adopt the scientific definition, and they become irritated when pupils do not do so. These teachers have not paused to consider the difficulties involved. Associations developed during early childhood are exceedingly tenacious. Secondly, in this case it is difficult for pupils to make the new association because an invisible substance is involved. Finally, as soon as pupils are outside the school, common usage tends to reestablish the old association.

Sometimes there is little value in making a struggle against common usage; the word "detergent" has gained such a specialized meaning that its dictionary meaning is all but forgotten. Sometimes a substitution is possible; "water vapor" serves equally well in place of "steam." Sometimes a teacher must give many experiences with "animals" so that pupils themselves broaden its meaning to include more than mammals.

A little common sense helps too. The perennial argument about "work" in physics classes can only antagonize pupils who know what makes them tired. It is easier and more accurate to qualify the word with "useful" or "accomplished" or some other descriptive adjective.

It is not to be expected that science teachers will agree upon the words to be introduced or ignored. It seems better, however, to be conservative, developing basic understandings rather than vocabulary. Too many words introduced too rapidly make science seem difficult and remote. But understandings make it possible for pupils to develop their vocabularies as they need new words.

Techniques for building vocabularies. A word worth introducing is worth introducing carefully. Once a teacher has decided that a term should be in the vocabulary of his pupils he should make sure that it receives adequate attention.

Miss Hendrickson demonstrated to her biology classes the effects of squeezing ripe puff balls. She explained briefly that from each of the particles given off a new mushroom plant could develop. She then named these particles "spores" both orally and in writing on the blackboard.

Miss Hendrickson asked her pupils to examine some of the spores with a microscope and then read about the life histories of mushrooms in their textbooks. At the end of the period, following a brief discussion of the reading assignment, she described the techniques for making spore prints from gilled mushrooms. The class planned a trip to a nearby woodland park to gather some of these mushrooms.

The next day the pupils took their trip and brought their mushrooms back to school, placing the caps on white cards. A day later, spores falling

from the "gills" had left prints on the cards. These were sprayed with artists' fixative and labeled appropriately.

Miss Hendrickson suggested that interested pupils could make additional spore prints, make drawings of mushroom plants, and read about the economic importance of mushrooms. Later she set the class at work on molds, raising some, noting the spores, and reading about life histories of molds.

Note the steps with which Miss Hendrickson fixed the word "spore" in the vocabularies of her pupils. First she provided a firsthand experience which probably served to recall similar experiences pupils had had previously. She gave the term orally and in writing. Examination through the microscope helped fix the association. Reading gave practice in associating the printed word with the actual spores.

Through the following days the pupils used the word frequently, hearing it, speaking it, reading it and writing it on cards and diagrams. They had opportunities to relearn the word if they forgot it from one day to the next. Finally the word was given broader meaning by its application to molds, and learning continued.

Such elaborate procedures are needed only for such words as are important enough to be used frequently by all pupils. Other types of situations may be set up to encourage the learning of new words without insistence that these be memorized.

Miss Neilson's seventh grade pupils brought in caterpillars and kept them in cages with suitable food. Well-illustrated books at different reading levels were placed nearby. As soon as the caterpillars began to pupate the excited pupils began reading the books. They prepared charts and wrote reports of their observations. Soon they were using such technical terms as "pupa," "chrysalid," and "metamorphosis" without any direction from Miss Neilson.

Though firsthand experiences are best for insuring proper associations, the previous experiences of pupils may also be used. The "teeter-totter" is familiar enough to all pupils to serve in the introduction of the word "fulcrum." However, it is difficult to be sure that all pupils have had certain experiences and even more difficult to ascertain whether the experiences have been meaningful. Past experiences should be relied upon only when necessary.

Photographs are useful in helping pupils recall past experiences. They also have limited usefulness when proper interpretations can be made from two-dimensional representations even though the material lies outside the pupils' past experiences. Diagrams and models may be used to reinforce associations but should not be depended upon to serve alone in vocabulary development.

Dictionaries and glossaries have but limited value in building a scientific vocabulary. Their definitions are given in words that may fail to produce a satisfactory image with which to make associations. These tools should be used to help pupils obtain a more precise definition of words that are already understood in part.

ORAL PRESENTATIONS

Though adolescents chatter freely, few of them speak well. Their discourses tend to ramble and are often pointless. Their limited vocabularies lack the words needed for the finer shades of meaning. Their self-consciousness hinders them when they face a group.

Oral reports of project work give valuable practice in communication. Pupils should be encouraged to use visual materials freely during these presentations. They may depend upon commercial preparations, as this boy is doing, or, better yet, they may design their own charts, models, and other exhibits they wish to use.

Science teachers can provide extensive practice in oral presentations. Talks may range in complexity from simple descriptions of observations to elaborate research reports. They may be spontaneous or carefully written out beforehand. Conditions may range from talks to a few classmates to formal speeches before large audiences, including radio and television audiences.

Brief reports in the classroom. Pupils often volunteer to make special investigations as part of their regular class work. Reports of their investigations may be integrated into the daily lessons.

Patrick volunteered to ask his father, a salesman for sound equipment, about the frequency ranges of various recording and play-back devices. Patrick's physics teacher, in his plans, allotted him five minutes following a demonstration of tape and wire recorders, and provided a follow-up experiment on the range of human hearing.

Time at the beginning or end of periods may be set aside for special reports that are not pertinent to the regular work of the class.

Susan had been studying the habits of morning glory blooms, tagging buds and keeping records of the times each opened and closed. When she was ready to make her report her science teacher set aside ten minutes at the beginning of the next science period for her presentation.

Some teachers set aside a regular time for reports of readings or incidental observations.

It was Thursday morning, time for seventh grade field reports. Colin described a pair of mourning doves he had seen in a cemetery. Margaret displayed some flowers she had picked on the way to school—flowers the teacher identified as Robin's plantain and pussy-toes. George told about the trout he had caught over the weekend and volunteered to post a picture of trout on the bulletin board so others would know what they were like. Marvin told of the large bumblebee that had entered his bedroom and the teacher explained how queen bumblebees look for new nesting sites in the spring. No other pupils had reports and so regular classwork was resumed.

A touch of formality is beneficial in all short reports. Pupils should speak from the front of the room and should be ready to answer questions from other members of the class. Thus they gain from the experience of facing their audiences. This technique also reduces the idle chatter that would result if pupils were free to speak from their seats; they come to the front only if they have something they think important.

Pupils rarely have difficulty with short oral reports. They cannot stray far from the point. They are able to retain class attention for the few minutes during which they are speaking. Nonetheless, pupils should be encouraged to use visual materials as much as possible while reporting. Visual materials give the speaker a sense of confidence, they help him keep his talk centered on one point, and they assist in holding class attention.

Jack illustrated his report on birdhouses with a sheet of cardboard in which he had made openings suitable for different types of birds. He also displayed a wren house and a bluebird house as two applications of desirable hole size.

Reports of major projects. Pupils commonly put a great deal of time and effort into project work. They need recognition for their achievements. Teachers may help them prepare reports that will be well received by their audiences.

Visual materials should be considered essential in all major presentations. These may be exhibits of actual materials, charts, blackboard drawings, lantern slides, models, tables, graphs and the like. Demonstrations that repeat processes employed are effective. There should be large printed labels so that the audience sees words as well as hears them.

Elinor, an eighth grader, had made a study of dandelion greens. In a brief introduction to her report she explained how she had become interested in the project and what her problem had been. She followed this with a description of dandelion plants, using fresh specimens and mounted specimens and a chart which she had prepared to illustrate her points.

Elinor turned next to the procedures she had used in her research. She had interviewed a number of European-born housewives who gathered dandelion greens each spring. From them she had found how plants with mild flavor could be distinguished from plants with bitter flavor. She illustrated her findings with charts and dried specimens. She mentioned that she had collected both types and cooked them and that differences in flavor certainly existed.

She then described the results of a field investigation in which she made a census of the two types in typical areas. She summed up her findings with bar graphs. She concluded that two distinct varieties of dandelions exist even though not recognized in the botany books she had read.

This report deserves special study as an example of the help that may be given other pupils. First, the subject was familiar to the listeners but a new and interesting aspect was being described. Elinor was talking from firsthand experiences; she was able to convey the spirit of the investigation and the picturesque details, and she talked with authority. Her charts and materials gave meaning to statements that were difficult to verbalize. Her graphs summed up her observations. Her specimens gave authenticity to her conclusions.

Pupils do not need to be highly articulate to present good reports. Usually, if a pupil is interested in his work, he can describe what he has done and what he has found out in adequate fashion. Should he have speech defects or should he suffer unduly from self-consciousness, the

teacher may help him organize his presentation to put major reliance upon demonstrations and visual aids rather than upon words.

Sixteen-year old Antonio had displayed a high degree of skill in the construction of a kymograph. His science teacher persuaded him to enter the project in a science fair and demonstrate its action. Though Antonio was unskilled in oral presentations, and very self-conscious about his foreign language background, he memorized a short introduction that was sufficient to set the stage for his demonstration. He followed the introduction with a deft dissection of a frog muscle which he subjected to a series of fatigue tests. Judges were much impressed with his techniques.

This report should be compared with one made by a boy with a serious stammer who tried to give a memorized talk on galaxies. It was a painful experience for everyone, the boy, the judges, and the audience. The boy may have been accomplished in this field, but no one could have been certain.

Some pupils prefer to investigate books and journals for information rather than do field or experimental research. They usually need guidance in the selection of suitable topics. Left to themselves, they are apt to choose such broad subjects as "jet planes" or "evolution." Their reports are made up of generalities and are rarely satisfactory. Much more suitable topics would be "Jet engine fuels" or "Development of common breeds of dogs." These topics permit the pupils to speak in specific terms and use more interesting visual materials.

Generally pupils should learn to speak from notes. This helps them develop a natural and relaxed manner of presentation. Exceptions may be granted to those pupils whose visual materials serve to give the talks direction. Memorized speeches are generally unsatisfactory; the pupils adopt an unnatural delivery and appear nervous lest they forget their lines. An oral reading of a written report is also to be discouraged though short passages may be read for special emphasis.

Book and film reviews. Oral reviews of books and films, when well presented, encourage listeners to read the books and view the films. Pupils usually need help in preparing such reviews.

As in all other oral presentations, visual materials are helpful. A pupil presenting a review of *Twenty Thousand Leagues Under the Sea* might well prepare a chart of the Nautilus to explain its features. A pupil reviewing Teale's *North with the Spring* might prepare a map to locate the regions described by the author. A pupil reviewing Sweazey's *After Dinner Science* might demonstrate one of the experiments described.

Pupils need help in understanding that it is better to present a

sample of a book in some detail than to describe the book superficially. A well selected sample shows the quality of a work and whets the appetite for more.

Julie, who liked to paint bird portraits, chose to review one of the biographies of Audubon. She concentrated upon what the book had to say about Audubon's painting techniques. She used some prints obtained from a calendar to illustrate these techniques. Then she read a brief section of the book to tell how Audubon obtained specimens for painting, and another section to tell how he supported himself while obtaining materials he needed to make his paintings accurate.

A teacher is justified in allowing pupils to use class time in preparing reviews. Pupils gain the impetus that they need to complete their reviews outside of school. In addition, the teacher is able to give suggestions about the organization of the review and the improvisation of visual materials.

Group presentations. Most adolescents feel more secure when giving talks as members of a group than when required to do so alone. They feel more at ease because audience attention is divided. They can accept responsibilities according to their knowledge of their strengths and weaknesses. Some self-conscious individuals will not volunteer to speak except in group presentations.

Four ninth grade boys gave a report on a balloon ascension into the stratosphere. The first boy outlined briefly some of the preliminaries of the ascent. The second boy prepared hydrogen with which he filled a rubber balloon to show buoyancy; he explained the dangers of hydrogen and the advantages and disadvantages of helium used in the actual ascent. The third boy displayed a chart showing the expansion of a partially filled balloon as it ascends and demonstrated this expansion with a rubber balloon in an evacuated bell jar. The fourth boy described the gondola, using both a model and a chart to illustrate its major features. The first boy resumed the floor and described the flight itself together with some of the findings of the expedition.

Some teams of pupils have prepared such interesting talks that they have been in demand by service clubs and other organizations. This is truly a fine experience for the pupils concerned.

In addition to presentations of the type described, groups of pupils may conduct quiz programs based on popular radio and television programs. Sometimes a group serves as experts and tries to answer the questions that come from their audience. Sometimes they serve as judges of the answers given by their classmates to questions which

they previously formulated. These activities add spice to reviews and drills as well as giving practice in speaking to the participants.

Science plays and assembly programs. Science plays can be rewarding to both audiences and participants. The plays need not be elaborate; those produced by a small group of pupils for their classmates can be little more than skits which utilize a minimum of properties and a maximum of imagination.

The chemistry class was working on individual and small group projects. Four pupils chose to dramatize Goodyear's discovery of the vulcanization of rubber. The first two scenes, or skits, humorously pictured the problems of wearing rain garments made of unvulcanized rubber. The garments were completely imaginary.

The next two scenes portrayed Goodyear's discouragement and final success. The last scene returned to the original theme with vulcanized rubber garments replacing those of unvulcanized rubber.

The production took about ten minutes. It was enthusiastically received by the other pupils who suggested that such dramatizations be used more often in the chemistry program.

Pupils like to use properties, scenery, costumes and special effects. These can be incorporated without making the production unnecessarily elaborate. A pâpier-maché skull and a retort make a pupil an alchemist, a blow on a paper carton is an explosion, a red lamp produces fire light. Pupils display a good deal of ingenuity in improvising these properties.

More elaborate plays, which require extra time for preparation, may be produced for the benefit of pupils in other sections of the same course. If sufficiently interesting they may be used for an all-school assembly.

One ninth-grade section wrote and produced a three-act play for an assembly program. Act One was set in a nineteenth-century home; two boys and two girls comment on the difficulties of life in the eighteenth century but are highly amused when one of the girls reads aloud some predictions for the twentieth century. Act Two was set in a modern home; two boys and two girls comment on the hardships of living in the nineteenth century but are amused at predictions for the twenty-first century. Act Three was set in a home a century hence and two boys and two girls comment on the hardships of the twentieth century. The curtain fell just as one of the girls began to laugh at some predictions she was reading.

Short plays are best written by the pupils themselves with little help from the teacher. They can get basic facts from textbooks and

USING MATHEMATICS REALISTICALLY

Physics and chemistry have always been known as quantitative in character. This is as it should be. But the role of mathematics in these courses has commonly been misunderstood. Instead of being used as a tool to aid in understanding, mathematics has all too often become an end in itself. The major aim of the courses has been the development of skills with certain mathematical exercises that are thinly disguised as "problems" but have little real significance to pupils.

The record speaks for itself. Relatively few pupils elect chemistry. Fewer still elect physics. And yet these are courses from which nearly all pupils could benefit The answer is not *less* mathematics, but rather *more purposeful* mathematics.

The metric system. In its drive to convert the American public to the metric system the science program has achieved practically nothing in half a century. Young people leave school with no conviction that the metric system has any special advantages.

The reason is obvious. Picture the first days of a pupil in physics. After a brief eulogy on the characteristics of metric measurements he is set to work with meter stick and calipers obtaining the dimensions of blocks in millimeters, centimeters, decimeters and meters—even kilometers—and is then required to convert these to inches, feet and yards. For home work he is directed to convert 3.627 inches to centimeters, and 7842.3 meters to miles. He is expected to memorize conversion constants to three and four significant figures.

The metric system should be used from the beginning in a natural way. Pupils learn its characteristics quickly enough and use the measurements in various operations as readily as they use English units. But there is no need whatever for the extended work with conversions that plague most pupils today. After a few weeks of experience with the metric system pupils gain a rough idea of the relationships between the two systems and can make approximate conversions. These are all that are generally needed even if both systems were in common everyday use. More precise conversions can be worked out as needed.

The Centigrade scale. All that has been said about the metric system applies to the use of the Centigrade scale. The best way to teach the scale is to use it. There is no value in confusing the pupils with conversions from the very beginning.

However, young people will need some basis for comparing the two scales. One teacher uses an interesting technique that seems effective. He provides Centigrade and Fahrenheit thermometers for all tempera-

ture measurements. Pupils are required to write both values, one in parentheses. Thus they automatically gain an idea of the relationship. The outcome is certainly worth the added cost.

Pupils will always discover the conversion formulas but these should not be taught deliberately. They have value only to the specialist who makes frequent conversions. They are learned with difficulty and forgotten with ease. Pupils should be shown how to draw two scales side by side with freezing and boiling points coinciding, and work out any needed conversions directly. This they can never forget if they know both systems to start with.

Formulas and equations. Science teachers commonly complain that their pupils do not know algebra. Sometimes this is true; pupils who elect only general mathematics have so little work with equations that their experience can be discounted. However, pupils who elect elementary algebra can deal with most of the linear equations that are developed in any realistic physics problems. Those who elect intermediate algebra can handle most of the quadratic equations that arise. *What teachers mean, when they complain of pupils' abilities,* is that their pupils do not know how to apply algebraic processes to the situations they encounter in science. It is the science teacher's responsibility to help them make these applications.

It is to be feared that science teachers do not always understand the mathematics they employ, or if they do they are so eager for results they take short cuts without proper explanations.

"I don't see how you can multiply pounds times inches," said a ninth grade girl during work with levers.

"Well, you can!" snapped her teacher. "See! I just did it."

This teacher's tart remark amused the class, embarrassed the girl, and exposed his own ignorance. Multiplication, as a form of repeated additions, permits no such hybrid joinings. But science teachers employ them constantly in "solving" problems.

Formulas, as the most used mathematical devices, are also the most abused. Too often pupils are required to memorize the formulas, apply them mechanically, and work out solutions blindly, even improperly, as was just described. The pupils are thus able to give a show of competence, but their competence is a thin shell that bears no weight.

Whenever possible, formulas should be developed inductively from data which the pupils collect themselves, organize to discover relationships, and express in their own ways. The pupils then know that the formula is but a short way of expressing a relationship and they

understand its limitations. They are also able to recreate it when needed.

Mr. Brewster provided each team of three pupils with an inexpensive voltmeter, an ammeter, and an unlabeled resistor. He varied the voltage supplied by a central control panel and the pupils made readings of current and voltage. Even before any class discussion, one group had noticed that for them the voltage was always four times the current and another group had noticed that the current was twice the voltage. The formula was quickly developed.

With the deductive approach to formulas, pupils commonly gain the impression that the formula controls the situation instead of merely describing it. This is especially common in chemistry; many pupils never understand the true significance of empirical formulas. It happens in physics also. Unfortunately, few pupils raise questions; it is easier to accept.

When deductive approaches seem dictated because of the nature of the mathematics involved, every care should be used to insure proper recognition of the true meaning of the formula. The teacher just cited uses a valuable technique in establishing the formula for resistances in parallel.

Mr. Brewster gave each trio of pupils a voltmeter, and ammeter, and two unlabeled resistors. Each team worked out the resistance for the resistors separately, in series, and finally in parallel. Exchanging resistors with other teams, each team repeated the measurements.

The pupils discovered immediately that resistors in series are additive. They discovered also that two resistors in parallel have less resistance than either component, and they could see why, but they could not work out the relationship. When Mr. Brewster showed them what it was, they accepted it immediately and applied it with satisfaction.

Graphs of equations. Pupils learn to graph simple equations in all their algebra and geometry courses. The graphs represent useful tools that too few science teachers utilize. The graphs should not come first; they should follow numerous applications when pupils are ready to study relationships in greater detail.

A graph of the formula $E = Ir$ shows the dependence of current on voltage; negative values should be used to show the effect of reversal of potential. Several curves, using different values for r should also be used to show the effect of changing resistance and to encourage speculation about the effects of reducing the resistance to zero.

A graph of $S = \frac{1}{2}gt^2$ shows vividly the relation of the distance

covered by a falling body to its time in motion. Substitution of negative values would give the history of the same body were it thrown upwards before it began to drop.

Pupils with sufficient background should plot ellipses, parabolas and other curves whenever these are encountered.

During the study of parabolic reflectors, Mrs. Lawson asked her pupils to plot on large pieces of wrapping paper a parabolic curve. She then showed them how to determine the behavior of light rays striking the surface. To help them visualize a parabaloid, she directed the pupils to bend a length of stiff wire along one leg of the parabola and twirl the resulting curve between their hands.

The use of significant figures. An understanding of significant figures is part of the study of measurement. The understanding is necessary for the proper selection and use of instruments, and for proper interpretation of results.

Once pupils have had experience in making measurements, they have little difficulty identifying the certain and uncertain digits in any value they have obtained themselves. They recognize quickly that a value of 63.2 centimeters obtained by a meter stick may actually range between 63.15 centimeters and 63.25 centimeters.

Pupils have more difficulty in recognizing the importance of significant figures. *If they are asked to identify all the uncertain digits in* their calculations, which they may do by underlines or circles as is shown below, the meaning becomes clear:

(a)	(b)
46.37	46
.76	.76
27822	276
32459	322
35.2412 or 35	34.96 or 35

Labeling the estimated digits in a calculation (the bold numbers above) shows the influence these digits have on the results. Multiplica*tion of a four-figure number by a two-figure number gives only two-*figure accuracy. The four-figure number could be rounded off as in (b), thus saving time in calculation. Or, if greater accuracy were desired, a more precise instrument would be needed to obtain both values to four figures.

They will quickly realize that a meter stick is as accurate for some measurements as a micrometer is for others, that weights need not be

Type of error	Cause	Effect	Method of detection	Means of minimizing
1. Accidental errors. Example: writing 64 as 46	Momentary lapse of attention	Unpredictable	Repeat measurements	Discard inconsistent data
2. Faulty techniques. Examples: Reading ammeter from angle	Lack of understanding of instruments used	Tend to be consistent for any one observer. Magnitude unpredictable	Use two or more observers	Gain understanding of instruments
3. Instrumental errors. Example: Thermometer that reads low	Instruments that are faulty	Consistent but whether high or low cannot be predicted	Repetition of measurements with two or more instruments	Standardize instruments
4. Limitations of instruments. Example: Graduate can be read only to nearest milliliter	Practical limits to number of subdivisions on scale	May be high or low within predictable limits	Analysis of limitations of instruments	Average results of several readings. If greater accuracy is desired, use instruments of higher precision
5. Lack of standardization. Example: Measuring two volumes of liquid at different temperatures	Failure to consider factors involved	Predictably high or low; magnitude often predictable	Analysis of conditions involved	Standardization of conditions when possible; application of correction factors otherwise

TABLE 15. *Characteristics of common errors that pupils encounter.*

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determined to four figures when in the same problem volumes can be determined to but two figures, and that four-place logarithms are adequate without interpolations for most mathematical work.

Theory of errors. Everyone who works with science should know about errors, their causes, their nature, their effects, and the means by which they may be eliminated or reduced. It is surprising that so little attention is given to this topic in secondary school science because even though the subject is a large one, there are phases that are meaningful to secondary school pupils.

The characteristics of the common errors that pupils encounter in their work are summed up in table 15. During discussions of methods to be used in experiments, pupils should consider these possible types of errors and decide upon techniques they will use to minimize these errors. Afterwards, when discussing data, the pupils should consider the influence of unavoidable errors on the data and estimate the magnitude and direction of the effects if possible.

Techniques for checking. The most useful checking technique is that of estimation. Pupils will develop the habit of looking ahead and approximating outcomes only if the teacher constantly emphasizes it himself. In almost every situation, before starting pupils at work by themselves he should take time to direct thinking along this channel.

Substitution techniques are useful for checking formulas and equations. Perhaps a pupil has derived the formula for temperature conversions; he now wishes to check it. He knows already that 100° C. is the same as 212° F.; substitution of one value should give the other. Or, to use values not employed in the original derivation, if he knows that −40°C. equals −40°F. he may substitute these values.

The substitution of zero for one of the variables in an equation sometimes shows whether a relationship is a valid one. If two unequal weights are suspended from a twine over a pulley, their motion will be governed by the following relation:

$$\frac{(W_1 + W_2)\,a}{g} = W_1 - W_2$$

When W_2 is reduced to zero, a becomes equal to g; in other words, W_1 and the string have the acceleration of a freely falling body. When W_1 is reduced to zero, a becomes equal to $-g$; in other words, the acceleration is that of a freely falling body but opposite that of the first case.

A useful technique, though not defensible in terms of pure mathematics, calls for the substitution of labels for the respective terms of

an equation. For instance, a pupil might wish to check his version of the momentum equation and his solution. He writes:

$$\text{Mom.} = \frac{W\,V}{g}$$

Substituting:

$$\text{Mom.} = \frac{\text{lb} \times \text{ft/sec}}{\text{ft/sec}^2}$$
$$= \text{lb} \times \text{ft/sec} \times \text{sec}^2/\text{ft}$$
$$= \text{lb-sec}$$

If he knows that momentum may be expressed as lb-sec he is certain that his units are correct and that his basic relationship is probably correct. This technique will not reveal, however, omissions or errors in constants such as the $\frac{1}{2}$ in $KE = \frac{1}{2} MV^2$.

Suggested activities

1. Divide the science methods class into committees each of which will be responsible for a section of a biology textbook or course of study. Determine the opportunities for providing mathematical experiences to the pupils as they study each section.
2. Plan a situation in which a mathematical formula is to be developed inductively. Present this lesson to the science methods class.
3. Assume that you are a physics teacher. Construct a test to determine the extent of mathematical skills possessed by the pupils.
4. Familiarize yourself with the complete mathematics program of a school system. At what grade levels would you expect the pupils to have reasonable mastery of basic mathematical processes?
5. Look for ways to use the metric system throughout a ninth grade general science program. Plan a lesson in which you introduce the metric system to the pupils. (Concentrate on a simple, direct, and interesting approach.)

Suggested readings

Hall, A. J., "Relations Between Science and Mathematics in the Secondary School," Bulletin of the National Association of Secondary School Principals, Volume 37, Number 191, Washington, January, 1953, pages 93, 94.

National Council of Teachers of Mathematics, *Multi-Sensory Aids in the Teaching of Mathematics, Eightieth Yearbook.* Teachers College, Columbia University, New York, 1945.

National Council of Teachers of Mathematics, *A Sourcebook of Mathematical Applications, Seventieth Yearbook.* Teachers College, Columbia University, New York, 1942.

Pearson, Stanley C., "Paper Models and Devices Useful in Teaching Physics and Mathematics," *Science Teaching Ideas II,* National Science Teachers Association, Washington, 1955, pages 23-27.

SCIENCE PROJECTS IN AND OUT OF SCHOOL

chapter 21

In my eighth grade science class this morning, David Skillman is observing and making predictions from the clouds and homemade weather instruments. Dick Grasso is soldering the connections for a one tube radio. Near the windows Kathy Baffa is placing cloth wicks from a bucket of water to some house plants to provide sufficient moisture for the weekend. In the darkroom Joyce Rutherford is learning to develop a roll of film and make prints, while at a table George Neil is completing his thirteenth article blown from glass. At the front of the room, Rosemarie Stompo is etching glass by using a formula consisting of cockroach powder, sulfuric acid and water; this information she found in a science magazine. Bill Robinson has made an incubator from store boxes, a light bulb, wire and a borrowed thermostat. Through a lens, he is observing the heart of a four day old chick embryo which he has just removed from his homemade incubator.

A relief map of Pennsylvania is being constructed from modeling clay by Norman Vandor. Don Littlewood has assembled an observation beehive with a glass enclosed ramp. He is surprised to find from his study that some of the bees live only several months, that the hive is air-conditioned by the bees moving their wings, and that one colony consisting of approximately fifty thousand bees makes a surplus of fifty to one hundred pounds of honey in one season. At the back of the room Dick Winn has set up an aquarium in which a pair of Paradise Fish are courting each other by spreading their highly colored fins intermittently." [1]

[1] From Getty, James H., "The Individual Project Method," *Selected Science Teaching Ideas of 1952*, National Science Teachers Association, Washington, 1953.

This is a picture of James Getty's general science class at work. Or rather, it is a picture of his pupils at work. Because this is not mass education; this is individualized instruction.

The project method, as used by Mr. Getty, is a recognized instructional technique. It should be in every science teacher's repertory.

THE NATURE OF THE PROJECT METHOD

The use of projects is not new in education. Teachers of academic subjects have assigned library research projects for generations. Teachers of vocational subjects have used projects as basic assignments ever since their courses were first developed. Science teachers, however, have in recent years brought out the potentialities of projects most fully by combining the elements of the practical problem and the academic problem.

What is a project? "There is nothing unique in the term 'Project' as it is used here . . . its present use is simply to indicate a problem, usually involving the use of apparatus and materials, undertaken by an individual or a group."[2] A problem may be as simple as making a collection of leaves. It may be as difficult as developing an original process for controlling electrolytic corrosion.

Projects are as varied as the pupils who undertake them. Most of these are simple; some call for little more than the ability to follow directions, to use elementary manipulative and academic skills, and to bring a job through to completion. But sometimes pupils do amazing work.

A project need not be new or original. "Even though a student may appear to be copying the design of a device, invariably he will inject a new idea."[3] Also it must not be forgotten that a discovery or invention that is well known in the scientific world may be original to an adolescent; he can benefit as much by his work as he would if his achievements were completely new.

Who should work on science projects. Any secondary school pupil may work on a science project no matter what his talents and interests may be. There are projects that will challenge pupils of the highest scientific aptitudes; there are projects in which non-readers may find satisfaction.

[2] Richardson, John S. and Cahoon, G. P., *Methods and Materials for Teaching General and Physical Science*, McGraw-Hill Book Company, Inc., New York, 1951.

[3] *Encouraging Future Scientists: Student Projects*, Future Scientists of America Foundation, National Science Teachers Association, Washington, 1954.

Special encouragement should be given to pupils of high scientific ability. These young people are not sufficiently challenged by the conventional program. They can work on projects during the part of their class time that they would otherwise sit through without benefit. The project method is an excellent way, perhaps the best, for helping talented young people make the most of their potentialities.

The publicity that exceptional youngsters receive for their achievements should not blind teachers to the fact that projects are good for all pupils. Pupils who have little interest in science find pleasure in projects that combine science with their special interests. Pupils who are considered "slow," which usually means that they are retarded readers, find in project work the satisfaction that is denied them in most of their school work; they may learn more from their science projects than from all other classroom activities combined.

Pupils who have expressed an intention of entering some scientific occupation should be given special encouragement to work on related projects. Thus they can learn much about the type of activity in which they will be engaging and they will discover much about their interests and aptitudes for this type of work. This knowledge will help them in making final decisions.

How the project method operates. An actual project begins with something a pupil wants to do—a device he wants to construct, a collection he wants to make, an experiment he wants to perform. But the project method begins earlier; it begins with the teacher's plans. It cannot be assumed that pupils begin work on projects spontaneously. They need help and guidance and occasional prodding if the project method is to be effective.

Most of the suggestions for project work originate with the teacher. During regular classwork he may point out possible ways to follow up certain topics. He may note a special interest and encourage a pupil to develop this interest. He may provide lists of suggested projects or take pupils to science fairs so as to see what other pupils are doing.

However, the teacher must not dictate what a pupil is to do or how he is to do it. Should he do so, he is merely making another assignment. Part of the value in project work comes from the opportunities to make choices and plan methods of attack.

Although newspaper stories give the impression of pupils spending long hours of their own time on their projects, most science projects are initiated and carried out during regular class periods. Sometimes one or two pupils work apart from the others who continue with their

regular class work. Sometimes the teacher permits all pupils to work on projects during portions of the class time.

Many science projects are carried out by two or more pupils working together. Sometimes an entire class works on a special project. Adolescents like to work together; they feel more secure. Many a pupil who would not undertake a project alone gladly teams up with a close friend.

Once pupils begin work, the teacher must give continued help—providing special materials, instructing in troublesome techniques, suggesting new approaches, pointing out progress and praising achievements. His role is not passive, he is as active as in any other type of teaching.

After projects are completed, the teacher has one more important responsibility. He must see that pupils receive deserved recognition for their achievements. He may arrange classroom displays and reports to other pupils or set up exhibits in school corridors and show cases. He can enter projects in science fairs and congresses, and contact local newspapers and radio and television stations to keep them informed of notable achievements.

The contributions of project work. Leland Wilson, a science teacher, tells the story of what projects did for a young girl. Mr. Wilson had an unusual opportunity to study this case because the girl happened to be his own daughter.[4]

Through the seventh grade Nancy displayed only a mild interest in science but in the eighth grade she learned about the Future Scientists of America. She was stimulated to begin a project on the study of bacteria. She followed this project with another and then another, each of increasing complexity.

Working on these projects brought Nancy into contact with specialists in medicine and biology and resulted in her being given an opportunity to do some work in a hospital laboratory. She found professional scientists willing to help a young person with a sincere interest. They encouraged her to try out some of her own ideas while she was working in the laboratory. From these contacts and as a result of the encouragement given her, Nancy tentatively chose for her future vocation the fields of medicine and bacteriology.

Mr. Wilson continues his account with an enumeration of the other benefits that derived from Nancy's project work. He mentions, for example, the change in Nancy's writing habits; instead of expanding

[4] Wilson, Leland L., "What It Did for Nancy," *The Science Teacher*, October, 1954.

paragraphs to produce an assigned number of words, she formed the habit of revising and rewriting to produce both conciseness and clarity.

Mr. Wilson referred to the way project work had filled Nancy's leisure time with meaningful activities. He was much happier to see her visiting libraries and laboratories than to know she was merely loafing with the "gang."

The contributions of science projects are as broad as the science program as a whole. The subject matter learnings constantly amaze judges at science fairs. Equally important as the facts and principles learned are the changes in ways of thinking and acting. These contributions may be summarized as follows:

1. Stimulating an interest in science
2. Satisfying scientific curiosity
3. Developing problem-solving techniques
4. Encouraging independent thinking
5. Giving practice in critical thinking
6. Developing an appreciation for the work of scientists
7. Making scientific principles more meaningful
8. Helping develop each individual to the utmost
9. Increasing self-confidence
10. Giving experience with tools and techniques of science
11. Filling leisure time to good advantage

INITIATING PROJECT WORK

Project work is almost always initiated by teachers. Occasionally an exceptional individual begins work on a project spontaneously, but such instances are rare. In some schools pupils are constantly at work on projects. In other schools there is never a project worth looking at twice. The difference stems from the difference in teachers.

Consideration for the nature of adolescents. It is not enough for the teacher to want to put the project method in effect. He must know how to make the method appeal to his pupils and how to attain worthwhile results from their work. He must know the nature of his pupils.

Adolescents have a number of characteristics that impel them to undertake project work enthusiastically. They like the freedom of action permitted them. They like the distinction of working on a problem apart from others in the class. They enjoy the status a successful project gives them with their peers and with adults. They like the favorable recognition and the publicity their projects earn for them. They also like to work with their friends.

In general adolescents like manipulative work and favor projects that enable them to make things. Most of them like to produce tangible things that they can look at with pride. They like the excitement of

experiments. Many like animals. They enjoy making and operating mechanical models.

On the other side of the picture, adolescents have a few traits that discourage them from project work. They have many immediate and pressing problems that take precedence in their minds over any form of school work. Young adolescents in particular are little concerned with the remote future and are apathetic about tasks that cannot be completed within a short time.

Adolescents are apt to underrate themselves and, although they might wish to duplicate some of the projects described to them, they feel inadequate to do so. They are afraid of failure and ridicule. They are particularly sensitive to criticism from leaders in their peer groups and may remain aloof from project work if the leaders refuse to undertake it.

Recognition of these adolescent traits makes it possible to introduce the subject of project work with reasonable expectations of success. However, not every pupil reacts favorably at the very beginning; different approaches are needed to fit different personalities.

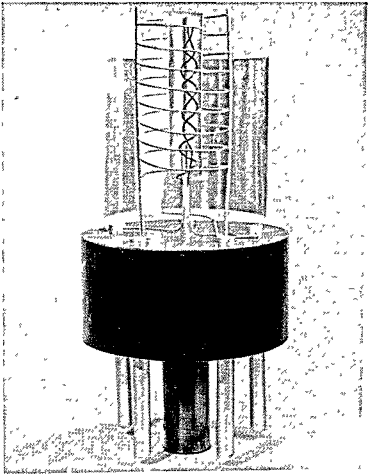
Stimulating pupils to undertake projects. There are any number of ways to encourage pupils to begin projects. There are mass methods in which all pupils are appealed to at once; these are most successful when pupils are accustomed to doing project work. There are individual methods in which one or two or three pupils are dealt with apart from the others.

The individual conference approach is often successful. The teacher notes through some contact with the pupil the existence of some special interest. The teacher arranges a conference with the pupil and explores this interest. The teacher may need do no more than propose ways the pupil may follow up this interest. But if the pupil is unaccustomed to individualized work of this nature, the teacher may need to give concrete suggestions for procedures.

In a second form of individual approach, the teacher describes to one or two pupils the nature of some project that would be useful in his classroom teaching. This may be the repair of some piece of equipment, the construction of some special device, or the creation of a chart or model. Many pupils enjoy being thus singled out and respond favorably. They usually prefer to work with close friends on such projects.

There are opportunities for individual contacts with pupils in science club work. Projects may be suggested on a service basis, as just described. Pupils with special interests may be encouraged to follow up their interests.

Some teachers call for volunteers to do project work. During the progress of a lesson they outline one or more follow-up studies and ask if any pupils would like to undertake them. Again pupils often volunteer more willingly if allowed to work with friends.



Products of project work are often excellent visual aids. This large scale model of a triode vacuum tube, made from tin cans, dowels, metal sheeting, plywood, and wire, has proved invaluable in the study of vacuum tube construction and operation.

Pupils are apt to be influenced by the examples of others. If a single pupil or a group of two or three pupils has undertaken a project and is working on it where others can watch, perhaps during a portion of the regular class period, the remainder of the class becomes favorably inclined towards project work. Perhaps at first they are more influenced by the consideration the others receive but once started it is possible that they will become interested in the project for its own sake.

The influence of example can also be utilized by requesting pupils who are working on projects to make interim reports. This awakens

interest in the projects early and keeps interest high until the completion of the reports.

Pupils who are working on projects for other teachers or for science clubs may be invited to describe their activities to a class. This may not be so effective as reports from members of the class but certain pupils might be challenged by some of the more elaborate projects.

Some teachers retain projects made by former students. Introduced at the beginning of the year they help pupils see the possibilities for similar efforts by themselves.

Many teachers are setting aside one unit in their programs for individual project work. They encourage pupils to propose their own problems but they also supply lists of possible projects that pupils may choose to work on. Such a unit is commonly placed rather early in the school year so that pupils may if interested follow up their projects through the remaining months. Other pupils, once acquainted with the project method, may find in following units possibilities for projects that will hold their interests.

It is always good motivation to take pupils to see science fairs. Commonly schools send bus loads of pupils to community and regional fairs. Many pupils are inspired by the entries. Most pupils come away feeling that they too could develop projects the equivalent of many of those they saw. However, science fairs usually come late in the school year and pupils do not feel any encouragement to begin projects at once. By the time fall has come the pupils have forgotten the impact of the fair. other interests have intervened, there may have been a change of teachers, and so the value of the fair has been lessened. Some way for reviewing the fair is needed, perhaps some of the programs, newspaper clippings and photographs on the bulletin board, or a viewing of colored slides may be effective.

Perhaps the one thing that teachers should not do is assign a project to a pupil. Such a project would be no different than any other assignment. It might, if properly chosen and if the pupil were receptive, stimulate the pupil to spontaneous efforts. But the chances are, if the teacher has not been able to appeal to the pupil in one of the ways just described, that he will resent the assignment and no good will result.

Providing ideas for projects. It has already been mentioned that many ideas for projects will arise from regular classwork and from a knowledge of a pupil's special interests. It is helpful, however, to know something of what pupils have done in the past in order to make suggestions. Many of these projects will be suitable for repetition and many will need only alteration to fit special needs.

Programs of science fairs give hundreds of suggestions. Lists of projects have been published in several sources, including the sponsor's handbook of the Science Clubs of America [5] and the pamphlet, "Encouraging Future Scientists: Student Projects." [6]

Science teaching journals contain descriptions of many projects that have been carried out by pupils. These usually represent exceptional achievements that lie beyond the abilities of most secondary pupils but they can serve as inspiration for the specially talented. Sometimes with modification they are useful for other pupils as well.

Textbooks often contain suggestions for projects, these are usually appropriate for pupils of average ability. Also valuable are the "do-it-yourself" science books written in increasing numbers for boys and girls. The familiar materials, the simple techniques, and the clear-cut directions make these books appeal to young people.

FITTING PROJECT WORK INTO THE PROGRAM

Class and group projects carried out as part of the regular class work are fitted into the program just as are other standard teaching techniques. The problem of encouraging completely independent work is somewhat different.

One or more pupils may be permitted to work on projects while other pupils carry out regular assignments. Rarely are these special pupils given all of a class period for project work. Instead they participate in most of the general activities of the class and spend only part of a period on their own interests.

The practice of excusing pupils from uniform class participation has been criticized on the grounds that these pupils miss important work. Actually the loss is negligible. These pupils do participate in the most important of the learning activities. If they are superior students, and many project workers are, they grasp the new material much more rapidly than the others and do their project work in time that they would usually waste if forced to work with the others.

Occasionally the retarded reader is excused from certain activities to work on his project. He may learn little from textbook or notebook but he will probably learn a lot from his project work.

As for the other pupils—each is a special case and only the teacher

[5] *Science Clubs of America Sponsor's Handbook*, Science Service, Inc., Washington.

[6] *Encouraging Future Scientists: Student Projects*, Future Scientists of America Foundation, National Science Teachers Association, Washington, 1954.

can decide whether he will profit more from regular class activities or from special project work.

As has been described previously, teachers also set aside class time for all pupils to work on projects. This does not mean that full periods are used for project work. It is usually better to begin each period with general reviews, summaries, drills, tests, or the presentation of new material. Only the last half hour or so is given over to project work.

Even as the remainder of a class pursues a planned program, individual pupils may be detached for short intervals to work on special projects. This boy is using part of chemistry period to experiment with the production of alloys in an arc furnace. The time he spends in regular classwork is sufficient to keep him abreast of the other pupils and to insure satisfactory achievement.

Adolescents find it difficult to concentrate intensely for much longer than twenty minutes and to hold them at their tasks for a greater length of time may result in waste of class time. However, all situations are different and there are occasions when general interest is so high that a full period may be utilized profitably.

During the remainder of the school day, pupils may find time for project work during study periods, noon recesses, and activity periods. When a teacher finds a pupil of special ability eager to work on a project it sometimes pays to make arrangements to have him excused from some of his study periods. This type of pupil usually has a good academic record and there is little difficulty in making the arrange-

ments. This pupil may then work on his project in the science laboratory even if a class is present. The presence of a pupil working by himself is rarely disturbing.

The noon recess is often a time when the science laboratory is free. If a teacher can be present for much of this period, perhaps bringing a lunch, many pupils are encouraged to work on projects rather than go home for lunch or engage in games. The teacher's presence is desirable, not for constant supervision but as a person to turn to when special problems arise. The teacher will also find it an excellent time to become well acquainted with the pupils.

Science clubs usually provide time for individual project work. After the business, if there is any, is out of the way, the remainder of the meeting becomes a laboratory period. This may happen two or three times a month.

During the remaining activity periods of the week, pupils may be expected to participate in other types of activities. The science teacher should encourage pupils to be members of musical organizations, serve on publication staffs, and join in dramatic productions. But there are certain pupils who will benefit more from science project work than from the activities in which they are often forced to participate. Special pleas should be made to let these pupils come to the science laboratories for the advantages the science program can give them.

As pupils develop genuine interest and skill with project work they begin to use time out of school on their projects. Many of them are willing and eager to stay after school if the teacher will let them. Whenever possible a teacher should keep his laboratory doors open in the late afternoon. He need not supervise the pupils closely. He may even leave the room for short intervals or go to faculty meetings if the work being carried on is not dangerous. His presence as a person to refer to in case of trouble is usually all that is needed.

Pupils will also put a great deal of time into their projects at home if they are sufficiently stimulated. The top winners in the national contests have probably put in three or four hours of outside time to every hour of school time. Such high interest does not come spontaneously. The teachers of these boys and girls have given them class time until they were started on their projects. Then they gave them special encouragement and permitted them to work in the science laboratories during extra-class time and after school. The more the pupils worked the more challenging became their problems and soon their project work began to dominate much of their waking hours. And so the teachers really provided out-of-school time without setting aside hours or making schedules for their pupils.

PROVIDING FACILITIES FOR PROJECT WORK

Many pupils do not engage in science project work simply because they have no place to operate. They live in small apartments or underprivileged homes. There are occasionally parents who forbid them or at least discourage them from activities that involve construction or experimentation. A number of pupils have possible facilities at home but do not know how to take advantage of them. It is the science teacher's responsibility to help pupils find places to work.

Science classroom facilities. To provide adequately for science project work a classroom needs free floor space, ample table space, special facilities such as electricity, gas, and running water, and storage space. Many classrooms are not well adapted for project work but alterations can often be made without destroying the usefulness of the room for regular class work.

Floor space is needed when pupils wish to lay out large sheets of paper for charts and friezes, and when they wish to utilize large pieces of panel board. Movable tables and chairs permit needed floor space to be provided in a few moments.

A large amount of table space is also desirable. Movable tables already referred to can provide part of this space. Wall benches can provide the remainder. The ideal table is solid, and not easily damaged by the activities that it will be used for.

Mr. Davenport built for his science classroom two tables patterned after picnic tables. The tops were of two-inch planks firmly attached to sturdy legs. When not in use for laboratory and project work, pupils sat at them as they would sit at the desks the tables replaced.

Almost any kind of project work could be done at these tables. They were not harmed by carpentry work; nails or drills passing through boards only made holes in the tops. Pounding did not loosen the joints or mar the oiled finish. Water did not stain them. Acid stains could be sanded off with a power sander. When the top became too battered it could be sanded off or turned over.

The tables were adaptable for many uses. If an overhead support was desired, a framework of boards could be nailed to the table. If a hole through the top was needed, a pupil could get on top and bore the hole. Strings could be attached with thumbtacks. Wires could be attached with staples or screw eyes. No other type of laboratory table has ever been so useful.

A good workbench with a carpenter's vise is essential, together with a set of tools in a cabinet that can be locked. A pair of saw horses have

numerous uses. A second workbench fitted for metal work is also desirable.

Storage space is always a critical need. Space is needed for the raw materials essential for project work—cans, bottles, lumber, wire, junk. Space is needed for the projects that are in various stages of completion—space where they can be kept out of the way of classes and yet be readily available when pupils want to work on them. Space is needed for storage of completed projects pending a science show in which they will be exhibited.

Architects almost never think of the storage problem. When facilities have not been provided the teacher may be able to requisition lockers and cabinets. Sometimes he can build cabinets. If there is a closet nearby, the administration might be receptive to the idea of its use by the science teacher. If there is unused space in the basement or attic, projects may be put into "dead" storage by encasing them tightly in shipping cartons.

Special project rooms. In recognition of the value of science project work, some new buildings have special project facilities adjacent to regular classrooms. In older schools, teachers have been able to convert preparation rooms and storage rooms.

David Kraus set up a special project room in one of the New York City high schools. His interest was in gifted pupils and the reasons he gave for the establishment of the room were:

1. *To provide added experience in activities. These should help the student explore his potentialities in the determination of his vocational choice.*
2. *To provide the student who will specialize in science an early start in the development of the intellectual, emotional and mechanical knowledges and attitudes which are part of the equipment of the scientist.*
3. *To provide opportunity for our better students to accumulate a record of accomplishment which is of far greater importance for college acceptance than the mere possession of high grades.*
4. *To give gifted children an opportunity to associate with each other.*
5. *To provide project work that would enrich classwork.*

The room was equipped with two binocular microscopes and three monocular microscopes. Additional supplies were obtained from various sources. The science teacher who had charge of the room was relieved of a school duty in compensation.

For the first year, nine gifted students, whose IQ was 130 or above, were chosen after consultation with teachers, reference to permanent records, and a personal interview.

The nine selected students were permitted to use the room during the last period of the day and after school hours. Project work engaged in required the approval of the teacher who helped each student crystallize his plan of work. At first the students did not keep good records but eventually they realized their importance.

The students submitted their problems and methods of attack at informal seminars where they sometimes literally tore each other's reports to pieces. Some of the pupils explained their projects to regular science classes and provided demonstration material to enrich and supplement the regular work of these classes.[7]

Other possible facilities for project work. Many pupils can work at home in their own rooms and in game rooms or workshops. They sometimes need advice about using their specific facilities and they may need cautions about the use of fire, acids, and other potentially hazardous items. If parents understand the importance of project work they sometimes help their children with the needed facilities.

In some cities, the museums, zoos and other science centers make available on a regular schedule work rooms for pupils with special interests. A teacher should investigate these possibilities and tell his pupils about them.

Unusual boys and girls, who have demonstrated high interest and competence in science work, have been invited by industrial laboratory heads and college science instructors to carry on project work in their institutions. While these are exceptional cases, a teacher, should he encounter one of these unusual pupils, may investigate similar possibilities in his own community.

Many students attend summer camps. While school projects are not a part of the summer camp program, the collection of specimens of insects, leaves, rocks, and the like is often part of the nature study activity. These collections can be used during the school year as the basis of pupil projects.

WHAT TO DO WITH PROJECTS

Pupils need recognition for their accomplishments. Ideally perhaps, pupils should work on special science problems just because they are interested; but boys and girls are human, and it is human to desire recognition for what one does.

Recognition may be no more than a few words of praise from the

[7] Kraus, David, "Starting a Science Project Room," *Selected Science Teaching Ideas of 1952*, National Science Teachers Association, Washington, 1953.

teacher. Better yet, recognition means increased status in the eyes of classmates and adults.

Recognition may be improved grades. Though many adolescents seem to be uninterested in grades lack of interest is partly a defense against the fear of failure. All pupils react favorably to high grades no matter what their outward reactions.

Recognition may take the form of tangible rewards, prizes, money, or scholarships. Because so few pupils can attain this degree of success it is better not to stress tangible rewards.

Reporting student projects. Some form of reporting on projects is needed so that the whole class can benefit from the experience of those who worked on the project. The length and type of the report is determined by the objectives of the project method. Sometimes the primary reason for projects is to give the pupil experience in working with materials and in planning and thinking in terms of scientific principles and applications. In such a case, a brief written or oral report will be sufficient.

Often the teacher considers the report to be an important part of the project and considerable planning and preparation are involved. A well-planned oral report will be informative to the class and will also help the student who is reporting to gain a degree of poise and self-confidence. Under most circumstances, the report should not be read to the class because first, most students have little or no experience in reading to a class and tend to be self-conscious, and second, the students have a tendency to copy the material for reports from an encyclopedia, college text or technical book and this results in the use of many difficult and unfamiliar words and a style unsuited to oral presentation. These factors will make the reading of reports a painful and monotonous experience for the class and the reader, with no satisfactory learning experience derived.

Instead of writing out the report, a few notes can be put on a card to guide the speaker, or a short outline can be put on the chalkboard where the student can refer to it and the class can use it for note-taking. The report should be given informally. It should deal with the purpose of the project, the materials used, the manner of construction and the problems encountered. The report should include a demonstration or explanation of the project and the scientific principles involved, and include practical application of the principles.

Interim reports as well as final reports are valuable. Interim reports enable pupils working on projects to organize their work more carefully because of the criticisms and suggestions of others. Interim

reports help awaken interest on the part of classmates as problems are outlined and methods of attacks are proposed.

Written reports on projects may be required by the teacher, and can be useful training to future scientists in the preparation of technical reports. The written report may be designed in the following form:

Title

I Summary
- A. Topic or problem investigated
- B. The purpose of, or reason for, the investigation
- C. Important results or information gained from the investigation
- D. Suggested action based on the results of the project

II Discussion
- A. Circumstances leading up to the project
- B. Acknowledgement of help received from other people
- C. Methods used in making the investigation
- D. Conclusions and the reasoning upon which these conclusions were based

III Appended Materials
- A. Drawings, photographs, graphs, tables, maps, calculations and other evidence supporting the project report
- B. Other material dealing with the project not included under another listing [8]

Providing opportunities for demonstration and display. Reports in the classroom need not be formal. An exhibition of a collection, a demonstration of an experiment, or the operation of a model, attended by a few words of explanation may be all that is needed. Pupils viewing the presentation should have opportunities for questioning and for suggestions.

Some types of project work lend themselves to static display. Flat materials such as charts, paintings, and leaf print collections may be tacked on a bulletin board. Many other items—models, results of experiments, collections of rocks—may be placed on side tables. It is often wise to exhibit one project at a time to center attention on one pupil's work and to avoid the inevitable comparisons that result when two or more projects are placed side by side.

Unusually good static exhibits—those that do not need demonstration—should be displayed to the entire school. Many schools have wall cases in the corridors for just such displays. Projects exhibited should be accompanied by labels explaining them.

[8] National Science Teachers Association, "Science Projects as Stepping Stones to Careers in Science," *The Science Teacher*, November, 1956.

When show cases are lacking there may be ways to provide opportunities for display.

Two of Mr. Appleby's general science classes made a study of a beaver dam a short distance out in the country. They collected evidences of the beavers' work and took pictures of dam and house.

Mr. Appleby put a table in the main foyer of the school, out of the main stream of traffic but accessible to everyone. Specimens were placed on the table and photographs were tacked to a panel of fiberboard behind the table.

Certain types of projects lend themselves to presentations at all-school assemblies. The projects should be of general interest. Materials displayed should be large enough to be visible from all parts of the auditorium. Special lighting and projection facilities may be needed. Programming should provide plenty of action, variety, change of pace, and humor.

The all-school science show, which will be described in a later chapter, provides excellent possibilities for suitable recognition. The date for the show is usually set for the spring so that all pupils will have opportunities to work on entries. Some teachers insist that all pupils provide at least one exhibit; other teachers make exhibition optional.

It is desirable that parents and other adults visit the show as well as pupils. For this reason the show may be given in conjunction with a P.T.A. meeting or an open house. The exhibits are set up during the day and all the pupils in the school are given opportunities to look at them. The exhibits are then left up for the evening meeting. All exhibits are more effective if the pupils who prepared them can be present to explain them.

Some science project work is newsworthy and photogenic. Local newspapers usually assign reporters to cover school activities. These reporters are happy to be informed about unusual projects and school science shows. They commonly bring cameramen with them to photograph the exhibits and the pupils involved. The resulting publicity is gratifying to pupils and to their parents.

Radio and television news reporters are also happy to learn about school science shows, winners in competition, and any special recognition that pupils achieve. Commonly, television cameramen visit science shows to record the activities, and program directors often invite pupils to bring their projects to the stations for interviews.

Superior project work should always be entered in regional, state and national competition. At these science fairs and congresses, pupils see what other pupils are doing and they talk with experts who point out the strengths and weaknesses of their work. Winners in such

competition receive substantial rewards that may help them in furthering their scientific study.

Finally, pupils should be given opportunities to write up their projects for publication. Brief accounts may be accepted by the school newspaper. A science newsletter may be planned specifically for printing reports of projects. Local and state science teachers' associations usually publish a newsletter or bulletin in which pupils' projects may be reported briefly. Junior academies of science may have special bulletins for this purpose. On the national level there are the journals of the several science teachers associations and the organ of the Future Scientists of America, an organization set up to foster pupil research.

Evaluating and grading projects. As pupils work on their projects the teacher should keep clearly in mind what project work is trying to accomplish. He will evaluate each pupil's work in terms of these objectives.

His evaluation is necessarily subjective. He can set up no rigid standards for judging the work of all pupils. Nor should he want to. Project work is important because it encourages individuality. Evaluation then must be in terms of the individual. A piece of work that represents a real accomplishment on the part of one pupil may be unworthy of the talents of another. Each project should be evaluated on its own merits not in competition with other projects, and with the abilities, interests, and background of the pupil given full consideration.

Suggested activities

1. Plan a project-centered unit in which the pupils work as one group or in small groups.
2. Carry out a project of the experimental research type that secondary school pupils would be interested in doing. Present a report of your findings to your methods class.
3. List titles of projects in biology, with short descriptions of each, which you would suggest to pupils with (a) high academic ability, (b) average ability, (c) low academic ability.

Suggested readings

Anselm, Brother J., "Making Projects Serve Our Individual Needs," *The Science Teacher*, October, 1955.

National Science Teachers Association, *If You Want To Do A Science Project*, Washington, 1954.

———. *Selected Science Teaching Ideas of 1952*, Washington, 1953.

———. *Science Teaching Ideas II*, Washington, 1955.

Richardson, John S., and Cahoon, G. P., *Methods and Materials for Teaching General and Physical Science*, McGraw-Hill, New York, 1951.

Science Clubs of America, *Sponsor's Handbook: Thousands of Science Projects*, Science Service, 1719 N Street N.W., Washington.

Wilson, Leland L., "What It Did for Nancy," *The Science Teacher*, October, 1955.

Yulish, Charles, "A Student Report Exploring and Developing a Science Interest," *The Science Teacher*, November, 1954.

Zim, Herbert S., "Opportunities for Pupils With Unusual Science Talent," *Science in Secondary Schools Today*, Bulletin of the National Association of School Principals, Volume 37, Number 191, Washington, January, 1953.

chapter 22 SCIENCE CLUBS

Science clubs have made it possible for large numbers of youngsters to find expression for their scientific interests. Young people are able to delve into special areas much more deeply than they can in regular classroom activities, receiving help and encouragement that they might not find were they to work independently.

Science clubs form the backbone of school-sponsored extracurricular activities in science. There is considerable evidence supporting the belief that science activities out of class compare favorably with regular curriculum work in terms of educational outcomes. In some instances the former may actually be superior.[1]

The science club presents a less formal atmosphere in which to work than does the usual classroom. With increasing informality comes a higher degree of cooperation between pupils and teacher. Work is more apt to proceed on a basis of mutual understanding.

In the science club, much more than in the classroom, learning is fitted to the abilities and interests of the individuals. There is no reciting and memorization of predigested material, and emphasis is upon independent study and individual initiative, liberally seasoned with opportunities for cooperative work.

There is carry-over from the science club to the classroom. Club members bring to their classes increased enthusiasm which tends to

[1] *Science Education in American Schools*, Part I, Forty-sixth yearbook of the National Society for the Study of Education, The University of Chicago Press, Chicago, 1947.

spread to non-members; they share their special learnings. Sometimes they present reports and exhibit their projects, all of which have teaching value to their classmates.

Within the club there are opportunities for adolescents to mature in their attitudes and their relationships to each other. They work together in program planning, in sharing responsibilities, and in developing special club projects. They have numerous contacts with adults in making arrangements for trips, in inviting and entertaining speakers, and in arranging for special help on their projects.

ORGANIZING A SCIENCE CLUB

Sponsorship of a club is not a responsibility to be undertaken lightly. A sponsor must be willing to devote considerable time and energy to the club, especially during the initial stages. He must expect to provide all the early planning himself; never can he expect the club to operate well if he gives it no thought from one meeting to the next.[2]

The sponsor cannot expect to be recompensed in any tangible way for what he puts into a club. His reward is the satisfaction he gains from helping young people develop their interests and special abilities. Most club sponsors find this experience sufficiently gratifying.

Facilities needed. Before a science club can be established, the administration must be willing to grant the use of certain facilities and to provide time for meetings and other activities. The club will need the use of one or more classrooms, depending upon the size of the club. It will need access to such special rooms as darkrooms and growing rooms. It will need occasional access to school shops. The club will utilize science department equipment and materials. The administration must grant permission for such use and be willing to underwrite the extra cost involved.

The administration must also provide time for club meetings, perhaps during the school day, perhaps after school, or in the evening, whichever is most practical. In the latter instances it must make arrangements with the custodial staff to cooperate with the club sponsor. The administration must also be willing to provide time for special activities—special assembly programs, science fairs and the like.

The administration can help greatly by freeing the sponsor from other responsibilities of an extracurricular nature. It can provide a small sum to supplement the club budget. It can provide stenographic

[2] Publications useful in organizing and maintaining a science club are listed at the end of the chapter.

supplies for correspondence and programs. It can allot a limited amount of school time for club trips and allow the use of school buses for such trips. Above all, it can give encouragement and show interest in club activities.

Type of club. The sponsor must make an early decision as to whether the club will deal with a wide range of science interests or be confined to a limited area. Generally speaking, the club which deals with science in its broadest aspects will succeed better than an electronics club or a chemistry club or a nature study club. The general science club fits the needs and interests of the greatest number of pupils, thus broadening the potential membership and insuring better selection of sincerely interested young people. Pupils interested in such narrow fields as radio, airplanes, and photography can operate within the structure of the general science club and still work on these special interests.

In larger schools, specialized clubs may be set up if there seems to be enough interest. Always, however, there will be pupils who do not share in these interests and are then denied participation in a science club even though they would benefit from such participation.

Size of club. The number of members in a club has an appreciable effect upon its operation. Too few members limits the special projects the club may undertake. Too many makes an unwieldy body that is too large for close contact with the sponsor and requires formal operating procedures.

Twenty to twenty-five members is considered by many sponsors to represent the best size but clubs with as few as ten or twelve are often successful. It is better to have a small club made up of genuinely interested members than to have a large club which contains inactive members.

If a large number of pupils wish to join a science club, and their interest seems sincere, attempts should be made to find a sponsor for a second club. In this situation it may be possible to set up a special interest club.

Selection of members. In forming a new club a sponsor may find it wise to select a nucleus of pupils who have demonstrated special interests in scientific work. This is better than broadcasting an appeal for membership which is apt to bring forth a number of pupils who are attracted only by the novelty of a new club and who make later operation difficult.

This carefully selected nucleus, which is in effect an executive committee, will help set up the general organizational pattern. These founding members may determine the qualifications for initiation and

standards for continuing membership—usually much higher than the sponsor himself would set. They assist in planning the general program and developing patterns of procedures to serve as guides in later years. From their ranks come the first officers, who are much more likely to be dependable than officers elected by a large, unconsolidated group.

Time for meetings. Meeting times vary in different clubs over the country. Some meet weekly, some only once a month. It would seem that monthly meetings should be supplemented by other activities to keep interest from cooling off between times.

Many clubs meet after school hours. Under some conditions this is practical and has the advantage of limiting attendance to truly interested youngsters. However, pupils who have jobs or who travel far on school buses are denied full participation.

Most administrators believe that an extra-curricular activity of high educational value deserves a place in the regular school program. They try to provide meeting times for clubs in a special activity period. A club sponsor must then be careful lest pupils attend meetings because these seem the least unattractive of the alternatives offered them.

Planning organization meetings. The first meeting of a new club serves to introduce prospective members to the type of activities in which the club might engage. Its purpose is to stimulate the enthusiasm of youngsters who are energetic and easily challenged by intellectual problems. This meeting needs careful planning, not to oversell the club, but to hold the attention of the young people who will benefit most by the club.

Examples of special projects may be displayed, or field trips described. Slides and films of typical activities are excellent; these may be borrowed from sponsors of other clubs and sponsors of science fairs.

The general organization of other science clubs may be described, not as patterns to be followed, but to illustrate how science clubs operate. From these illustrations future members will gain suggestions they may wish to incorporate into their own organization.

During the first several meetings of a club, the members must be concerned with details of club organization. This is a phase that does not appeal to many adolescents, particularly to those who are eager to begin experimenting, doing photography, and taking field trips. It may be wise to do much of the organizational work through committees who report their decisions to the membership at the regular meetings.

CHECKLIST FOR THE FORMATION AND MAINTENANCE OF SCIENCE CLUBS *

I. First Meeting
  a. Temporary officers — at least a president and secretary—selected
  b. A committee is appointed to formulate a constitution

II. The Meeting of the Constitution Committee
  a. What shall be the aim and purpose of the science club?
  b. What shall be its name?
  c. Membership
    1. Who can become a member?
    2. What must a boy or girl do to become a member?
  d. Meetings
    1. When shall they be held?
    2. Where?
    3. How often?
    4. Who shall call special meetings?
  e. Money
    1. Shall we pay dues?
    2. How much?
    3. Can we levy taxes?
    4. How? How much?
    5. For what shall the money be used?
  f. Expelling members
    1. For what reason or reasons?
  g. The business program
    1. How long shall it be?
    2. What shall be the procedure?
  h. The club program
    1 What kinds of activities shall the club have?
    2. Who shall decide upon and arrange these programs?
  i. Officers:
    1. What officers shall the club have?
    2. What will be their qualifications?
    3. When shall elections take place?
    4. What shall be the officer's duties?
    5. Can an officer be removed from office? How?
    6. Shall officers filling positions left vacant be appointed or elected? And how?
  j. Any other regulations you think important to put into the constitution

III. Second Meeting (and probably the third)
  a. Presentation of the constitution
  b. Discussion and revision if necessary
  c. Adoption by majority vote
  d. Election of officers
  e. Business meeting to get the club's program underway
  f. Setting up a year's program

* Adapted from an outline prepared by Morris Meister, in *Modern Science Teaching*, by Elwood D. Heiss, Ellsworth Obourn, and Charles Hoffman, Macmillan, New York, 1950.

Page 552 lists suggestions for the business to be taken up in the first two or three meetings. This business could well be apportioned out over many more meetings, with but ten or fifteen minutes of each meeting devoted to consideration of a limited number of topics. In the meantime, the club may take a field trip, see a special film, watch the sponsor demonstrate a Geiger counter, participate in printing pictures, and be entertained by a committee presenting a "Chemical Magic" show.

PLANNING THE CLUB PROGRAM

Club members should be responsible for the program almost from the beginning. If the initial membership is small, all members may sit in on the planning, otherwise a special program committee should be appointed. This committee should have the power to appoint temporary committees to take responsibilities for special meetings and special events.

Preliminary decisions. The first meeting of the program committee each year must give attention to organizational problems. The list given on page 552 can serve to set the agenda for the meeting that organizes a new club. It may be used in succeeding years to call attention to matters needing reconsideration. From the discussion of the items on the agenda the committee may set general or special meetings to deal with the problems raised.

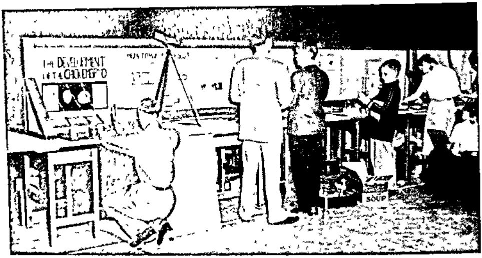
Setting up a program for the year. A science club needs a forward look; it cannot succeed with day-to-day planning. On the other hand, adolescents cannot work out details for months in advance; their interests tend to be more immediate. It is better to prepare a skeleton which will be filled out as the year proceeds.

One procedure that has worked well with adolescent planning groups is to encourage them to prepare a calendar on which is listed one special project or meeting for each month. If advance arrangements must be made for any of these special events, responsibilities are delegated immediately. Otherwise details are worked out a month in advance by the planning committee at its regular meetings.

The sponsor may make suggestions for these special events but decisions should be left up to the members. The sponsor is an advisor, not an officer in the club.

Among the special events that may be listed are special films, guest speakers, and visitations. Committees may be appointed to select the films and order them, to contact possible speakers, and to make arrangements for visitations. This should be done well in advance.

The club may undertake service projects, perhaps for the science department, such as helping with an inventory, or for the school, such as planting bulbs. A club may take on occasionally such a project as preparing Christmas decorations for the foyer of the school; one club decorated a tree with flasks of colored water and other science materials to produce a novel but effective display.



Much of the responsibility for this science fair was assumed by a science club. Note the easily stored table tops and tackboards, which permit display space on both sides. Table tops and tackboards are covered with short lengths of crepe paper in contrasting colors, which delineate the space available to each exhibitor and at the same time provide him with a colorful background for his display.

The club may set up special science exhibits; it may produce an assembly program; it may sponsor a school science fair. It may add regular services such as the maintenance of a science bulletin board in the corridor of the science department, the preparation of a science column for the school newspaper, or the presentation of a regular series of science radio programs.

A club may wish to raise money for some special purpose. It may ask for the refreshment concession at athletic events or sell things by house-to-house canvass. One club, in keeping with its science theme, dipped pine cones in various salts and sold them to people to burn in fireplaces for special displays of color. The social needs of adolescents should not be neglected. The science club may well have at least one party a year.

Below are the special events in which two science clubs engaged during a school year:

A chemistry club. The activities of one chemistry club included the following places visited in one year:

1. A rubber mill
2. A brewery
3. A modern hospital
4. The medical laboratories at the Mayo Clinic
5. A patent medicine and food products manufacturing plant
6. A sewage disposal plant
7. A modern farm implement factory
8. A plant which produces heating units and air conditioning systems
9. A soft drink factory
10. Two ice cream factories and a milk plant
11. Local gas factory
12. A modern foundry

All visitations were preceded with at least one discussion and preparatory meeting and followed by a discussion of the principles and applications of chemistry that were observed.

The club presented two programs—one before the pupil body and one before the Mothers' Club or P.T.A. A quarter hour of the assembly program was presented over a local radio station.[3]

A general science club. A general science club carried out the following activities in the course of a year:

1. Attended annual Dahlia Show.
   a. Group then discussed how flower shows were conducted.
2. Attended a "Bird Lecture."
3. Visited Franklin Institute and Fels Planetarium.
4. Had a picnic which included a "Nature Hunt," races, games and a "Treasure Hunt."
5. A geologist visited the group and told them about volcanoes and earthquakes.
6. A herpetologist visited and brought some snakes which he talked about.
7. Had a movie party where the students brought their own movies and operated the projectors.
8. Took a trip to the Maryland Academy of Science.
9. Visited a zoo and had a contest on animals.
10. Visited an airport and took a ride in an airplane.
11. Took a trip to Hopkins Botanical Gardens.
12. Took a sight-seeing trip to Washington, D. C.
13. Held a "Hobby Show."
14. Prepared own flower show.

[3] From Hoff, Arthur G., *Secondary-School Science Teaching*, The Blakiston Co., Toronto, 1949.

15. Had a lecture on birds and bird calls.
16. Held a "Science Experiment" afternoon.
17. Arranged displays for the school bulletin boards.
18. Had a "Curiosity Meeting." [4]

Planning general meetings. The basic program for the year determines in advance the nature of a number of regular meetings. One meeting, for instance, is usually needed for the initiation of new members. Visitations take up other days. A science show, if one is sponsored by the club, occupies another day. All such meetings will be in the hands of special committees.

Portions of other meetings will also be determined in advance by the master schedule. Films and guest speakers take up the major part of the meetings in which they are employed; again special committees would have made arrangements in advance for these features. Portions of a number of meetings will be used in preparations for other events—assembly programs, initiations, and the like. These meetings will be guided generally by the respective committees.

The business portion of general meetings is in the hands of the president of the club. The sponsor may help him prepare the agenda for these meetings, giving advice as to which matters may go to committees for action and which should go before the membership body for discussion and vote. The sponsor should try to keep the agenda from becoming cluttered with trivia that result in idle chatter. He should try to hold the business to one or two matters per meeting, recommending several short business sessions rather than a few long ones.

The sponsor is usually responsible for the first meeting of the year. This meeting should proceed with vigor to set a pattern for later meetings. Films or slides of work done the year before interest pupils, who enjoy seeing themselves on the screen, and stimulate them to try to better previous achievements.

Some of the same considerations that govern good lesson planning should govern the plans for club meetings. No one activity should be carried on for too long a time. A ten-minute business meeting and a twenty-five minute film make a good pairing. After a fifteen-minute talk by a guest speaker there may be a ten-minute question period; the remainder of the time may be used by one or two demonstrations by club members to show the guest what the club does. A committee may present general plans for a club project for ten minutes, a free discussion period may follow as long as needed, after which pupils volunteer for sub-committees and break up to begin planning their activities in the project.

[4] From Moody, Rosalie, "A General Science Club," *Baltimore Bulletin of Education*, March-May, 1951.

Variety in programming is always desirable. One week a field trip may take up the meeting time. The next week might be devoted to work on special projects. The next week some bit of entertainment might enliven part of the meeting. One week might be very serious; the next week the meeting might include some humor.

MAJOR CLUB PROJECTS

Young people find much satisfaction in activities that bring everyone together for constructive work. Such projects do much to weld membership together into a loyal body that takes pride in the organization.

Establishing a science museum. Establishing a science museum is one example of a project which the science club might undertake. The science museum does not have to be a dark room cluttered with mounted animals and obsolete equipment that is not currently in use. Nor does it have to be an elaborate exhibit of expensive apparatus. A school science museum might well consist only of simple displays placed on a table or in a glass-front cabinet. The corridor often serves as a museum, but a separate room, if available, makes a much more desirable arrangement.

One of the chief advantages of a small area for display purposes is the need to change the display at regular intervals. These frequent changes can be made by members of the science club. An exhibit that has been on display for a long period of time loses its value.

Displays attract attention and arouse questions. This in turn creates an interest which can result in improved classroom work. If the display has been collected or set-up by science club members, it can be used directly in the science class. Club members can set up their exhibits in the classroom and then make up questions to be answered by the rest of the class. Displays made by club members can also serve to initiate questions from other students.

Projects and collections that become a permanent part of the museum can be used as illustrative materials for future classes. Not only does it reduce the cost of science instruction, but it also provides materials that are unobtainable at supply houses.

Science assembly programs. One of the functions of school assemblies is to give the pupils an opportunity to plan and present programs for the rest of the student body. The science club is often in the best position to assume the responsibility for such programs. Science classes and clubs have the material for a host of novel as well as educational programs.

The program material can be taken from the various branches of science or it can revolve around a certain topic. A few topics that can provide material for assembly programs are:

1. Electrical household appliances
2. Air pressure
3. Uses of nuclear energy
4. Combustion
5. Science hobbies
6. Electronics
7. Dry ice experiments
8. Conservation
9. Meteorological equipment and weather observations
10. Life in a drop of water
11. Community health
12. Consumer education
13. Science and magic
14. Men of science
15. Experiments with sound, light, etc.
16. Science vocations [5]

Maintaining a bulletin board. Science club members can be responsible for maintaining the bulletin board in a classroom. The bulletin board should be attractive and have appropriate captions. The display might enhance the regular classroom work.

Writing for the school newspaper. Each member may be responsible for writing up a science news article that would be submitted to the school newspaper. The article should be scientifically accurate, interesting, and well written.

Presenting demonstrations or exhibits to the elementary school. Whenever a science club has an interesting exhibit or demonstration within the realm of understanding of elementary school pupils, the members should be encouraged to present it to the lower grades. This would help to stimulate science interest in the elementary grades.

Making demonstration materials for the science classroom. Science club members can make materials, such as homemade lantern slides or simple demonstrations, apparatus, microscopic preparations, preserved specimens, picture files, charts and diagrams. These may be kept and enlarged upon from year to year for the use of the entire school.

Maintaining an inventory of science materials and equipment. A helpful service for a club to perform is to check science supplies and

[5] Marshall, J. S., "A Program for Increasing Student Interest in Science," *School Science and Mathematics*, November, 1954.

provide each teacher in the building with a current inventory of equipment and materials in the building. This would not only be a time saver for teachers but would assure maximum utilization of such materials.

Repairing and maintaining science equipment. Many pieces of equipment can be repaired without too much difficulty if the science teacher has the time. Often the equipment can be repaired by science club members who have mechanical aptitude. Along with this, science club members can help to keep science materials orderly so that they can be found when needed.

Setting up demonstrations for the science teacher. Science club members can assume the role of laboratory assistants. They can be very helpful to teachers in setting up apparatus in preparation for a demonstration or for a laboratory period. They can also dismantle and store the apparatus after use.

Finding resource people in the community. Many club members come in contact with outstanding scientists in industry and in universities. These individuals may be invited to speak at assemblies and regular club programs. Science teachers should evaluate these individuals before they are approached by science club members.

EXAMPLES OF SCIENCE CLUBS

A junior high science club.[6] The Grant Science Club is the product of over fifteen years of experience. Through the years it has gradually evolved to its present form, which has proven most successful for the junior high school level. The club is limited to twenty-five members and the only basic requirement for entrance is a keen interest in science.

Selection of new members. Prospective candidates assemble after school for a brief meeting at which they learn the story of the Grant Science Club and its activities. They are told that if they wish to join they must submit within a week's time a sample science project of their own creation—a scrap book, a nature collection, a report of work with a chemistry set, or the like.

On the assigned day, the projects are displayed after school. Each is identified only by a number. Each club member examines them and rates them from 1 to 10. The ratings are averaged and the projects are listed by rank. An arbitrary dividing line is established; this fluctu-

[6] Prepared by Charles G. Gardner of the Grant Junior High School, Syracuse, N. Y., who has sponsored the club since its origin.

ates depending upon the numbers which can be taken in to fill the membership of the club. Applicants receive notification slips and return to pick up their projects.

Successful candidates are invited to an interview by the club membership committee, which tries to find out their reasons for wishing to enter the club, their special science interests, and something of their respective personalities. The club members take this very seriously and make a careful evaluation. If a candidate does poorly on the interview he is personally interviewed by the sponsor. The sponsor talks with the home room teacher of each candidate to determine whether there is any reason why this person should not join the science club.

Personal letters signed by the club sponsor and the club president announce the decision of the club to the successful candidates and invite them to the next meeting at which they are initiated. Harmless initiation tricks are played on the blindfolded initiates, under the careful supervision of the sponsor, to the great delight of the members.

The new members are then officially welcomed into the club and given their Third Class requirement card and a mimeographed guide sheet. Later they are given a special briefing session after school.

The point system. The club operates on a point system. Members are awarded points for various types of activities. Some of these activities are listed below, but members may do many other things with the approval of the sponsor. A careful record of points earned by each member is kept in a notebook by the sponsor.

1. Perform an experiment and write it up with a drawing (5 points)
2. Give book report on scientific book or booklet (1 to 10 points)
3. Report on club trips (1 to 10 points)
4. Operate the balance scale (5 points)
5. Operate the microscope (10 points)
6. Know the 25 common elements and their symbols (10 points)
7. Construct laboratory equipment (up to 25 points)
8. Carry out a research project (up to 25 points each)
9. Do committee work (points awarded according to judgment of sponsor)
10. Participate in science show and congress activities (points determined by the sponsor)

In order to eliminate efficiently the joiners with no real interest in science, there is a requirement that new members must earn 25 points by the end of the first month and 75 points by the end of the second month, in order to remain in the club. Thus the sponsor is assured of an active group.

Through various projects and through participation in club activities,

members can progress in rank. The ranks are based on both point requirements and special requirements.

Point requirements

Beginner:	0- 24 points	First Class:	150-224 points
Third Class:	25- 74 points	Expert:	225-349 points
Second Class:	75-149 points	Master:	350 points

Midux Club (silver pin): 1000 points

Special requirements

Third class

1. Know the location and names of chemicals and equipment.
2. Pour acid from a bottle correctly.
3. Wash a test tube correctly.
4. Light and adjust a Bunsen burner and boil water in a test tube.
5. Operate the balance scale.
6. Know the proper form and write out one experiment correctly.
7. Read one science booklet and write a brief report.
8. Be on the bulletin board committee at least once.

Second class

1. Know the twenty-five important elements and their symbols.
2. Know the parts of a microscope and how to use it.
3. Take an active part in one club program.
4. Read one science book and write a brief report.
5. Take at least one club trip and write a report.
6. Be on the show case committee at least once.
7. Neutralize a solution of hydrochloric acid with a solution of sodium carbonate and evaporate.

First class

1. Cut glass tubing, fire polish the ends and draw it out. Make a right angle bend. Blow a bubble in the end of the tube.
2. Change cotton into sugar. Ask permission first.
3. Work out a science problem given you and show that you think and act like a scientist.
4. Read and write a book report on one of the books listed.
5. Help to train and pass a new member on some requirement.

Expert

1. Memorize a group of common formulas.
2. Pass a fundamental course in photography and develop and print a roll of film to the approval of the sponsor.
3. Take part in a science club school service project.
4. Keep a complete record of the weather for 14 consecutive days and compare each day with the official forecast.
5. Select an insect, a bird and an animal. Write a life history of each one.

Master

1. Enlarge a picture, using the school darkroom.
2. Set up the distilling apparatus and separate a mixture of alcohol and water.

3. Make a labeled collection of 15 or more samples from some one field of nature.
4. Construct a biological model using papier mâché.
5. Make a list of 25 jobs that require much science training.

A science field trip club. Wallace M. Good, Science Teacher, Wyandotte High School, Kansas City, Kansas, organized a field trip club in February 1952 which has grown in scope, usefulness and influence since then.

"The club is an extra-curricular activity with five basic programs:

1. Teaching methods for conducting original research
2. Teaching methods for writing and publishing research papers
3. Providing for study under professional scientists
4. Developing interest in advanced study through attending science meetings, conducting radio programs concerning work of the field club, and presenting original research to science organizations
5. Developing a proper attitude toward the importance of the liberal arts as prerequisites for professional specialization.

"At the heart of the program lie the field trips. These trips are carefully outlined by the sponsor and directed by a staff member of a college or university in the Kansas City area. The staff member is a Ph.D. in some field of science and accompanies the group. Field trips are taken during the year into the six-state area of Oklahoma, Arkansas, Kansas, Missouri, Iowa and Nebraska. The trips range in length from one day to week-end length."

The outline of a typical field trip taken by the members of the club include the following steps: the purposes of the trip are outlined, a locality for work is chosen and the equipment for the trip is assigned and checked out to each member. The actual trip includes a road census taken by each member from Kansas City to the point of destination, general collecting, and working on a special project. Time is taken from the schedule for recreation. The follow-up activities involve laboratory work, project reports which are submitted to the sponsor, as well as writing up field notes. A radio report concerning the trip is broadcast from one of the local radio stations.[7]

A senior high science club. The Science Club meetings of Kenmore Senior High School are held weekly on Thursday evenings starting at 7:30 P.M. Students spend their time voluntarily working on science projects under the supervision of Miss Louise Schwabe, the sponsor of the Biology Club, and Rolland Gladieux, who sponsors the Physical

[7] Good, Wallace M., "A Science Field Club," *Science Teaching Ideas II*, National Science Teachers Association, Washington, D. C., 1955.

Science Club. The clubs have no dues and the membership is based upon interest and aptitude in science.

Since the Kenmore Public Schools are located in a heavily industrialized area, many scientists and engineers are available to give the club members technical assistance in their various science projects. In addition, special equipment and supplies are given to the pupils if needed. However, pupils are encouraged by industrial concerns to make their own apparatus. War surplus equipment and materials have been used to a great extent.[8]

A "micro" club. "'Magnify your science interest' might well be the slogan of this science club. The club, in an informal atmosphere, encourages pupils who are interested in science to pursue their interest through the medium of magnification. The club is an extracurricular activity and approaches the study as a hobby interest. Such biological concepts as the food chain, balance of life, ecological factors, the role of the herbivore and the carnivore, are beautifully illustrated in our study of tiny fresh water plants and animals. Parasitism and symbiosis are other understandings that are given real meaning."[9]

Suggested activities

1. Visit a science club and observe its operation. Report your observations to your methods class for discussion.
2. Obtain a year's program of a science club. Note the variety and balance of activities. Classify the activities under headings such as the following: social and entertainment activities, field trip activities, service projects, and seminars. (Use additional headings as needed.) Propose other activities which might strengthen this program.
3. Plan the organization meeting that you might use in establishing a science club.
4. List the promotional devices you can use to stimulate membership in a science club.

Suggested readings

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SCIENCE FAIRS AND CONGRESSES

chapter 23

Can you visualize an area about the size of an athletic field, filled to capacity with over fifteen hundred boys and girls, each with table space about two feet deep? Each of the fifteen hundred boys and girls comes from schools within a one hundred mile radius and each has his or her own exhibit on one of the tables. The projects submitted by each of the participants have been judged as outstanding by the teachers in their own school. In addition, visualize in the athletic field hundreds of visitors, who may be the parents of the participants, teachers, prominent scientists, pupils, or just individuals interested in what is taking place. From the outside looking in, one might think it was a church bazaar on a large scale. Actually, a science fair is difficult to describe. It must be seen to be appreciated.

Some science fairs involve not only exhibits but also lecture-demonstrations. This type of science fair which involves both the line-up of projects and lecture-demonstrations has been called a science congress. This is a fine distinction, for many school science fairs include the presentation of talks along with the exhibits. In general, a congress stresses the lecture-demonstration rather than the individual exhibit.

WHY SCIENCE FAIRS?

Purposes of a science fair. The Denton County Science Fair, held on April 4, 1952, at the County Fair grounds in Denton, Texas, listed the following as its purposes:

1. To focus attention on science experiences in school.
2. To stimulate a greater interest in science by all pupils.
3. To stimulate a greater interest in scientific investigation over and above the routine class work.
4. To provide stimulation for scientific hobby pursuits.
5. To offer an opportunity for display of scientific talent through exhibits and demonstrations.
6. To recognize and commend youthful scientific talent.
7. To provide constructive suggestions for teachers and pupils of science.[1]

The above is an excellent summary of the purposes of science fairs. The most important purpose of the fair or congress is to stimulate and encourage interest in science on the part of young people. This may be brought about in a number of ways. The actual presentation of the project by a pupil may bring to this pupil a deep sense of satisfaction and accomplishment resulting in a strengthened science interest. The participation in the fair, with the opportunity to see the work of other pupils, meet and talk with the judges and other adult scientists may stimulate the young pupil's interest in science. Finally, if the pupil is fortunate enough to be a prize winner in the fair, his success may do much to start him on his way to successful science studies.

Values of science fairs. Science fairs provide an excellent method of sharing the science projects of individuals, small groups, or entire classes with the other students within the school, other schools in a community, parents and other members of the community, and the schools of the entire regional area.

Science fairs can be a motivating force for individual projects as well as for class work. Many of the classroom activities come to an end with only the class members seeing the results. To some pupils it must seem like a "hollow victory" not to have other boys and girls praise a successfully completed project. A boy who makes a motor out of wire, nails, and a battery swells with pride as his classmates praise it. Much the same feeling can result from exhibits and demonstrations at a science fair.

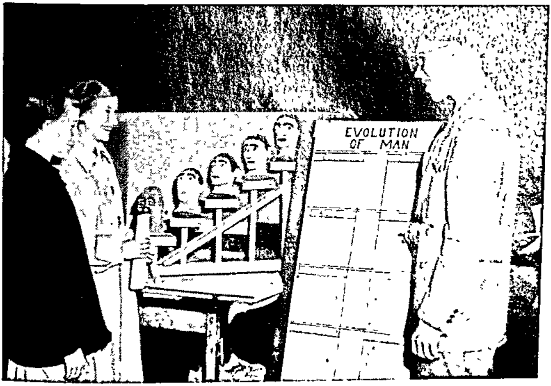
Not only does a science fair stimulate the pupils and make their science work more meaningful, but it helps to do the same for the teacher. Teachers can be stimulated to do a better job of teaching through science projects which are entered in fairs.

Another value of the fair is that it utilizes the time of youth in a constructive way. With an excess of leisure time, especially in urban

[1] ...nes, Norman R. D., "Science Fairs—Science Education in the Com-..." *Bulletin of the National Association of Secondary School Principals*, ...1953.

centers, there has been an increase in juvenile delinquency. Science fairs are not the total cure, but they can be one of the ingredients that will help effect a cure.

Fairs provide a wonderful opportunity for discovering and encouraging science talent. The participants in the state and national fairs have a chance to win prizes of part or full college scholarships or to be recognized and given aid by organizations, colleges or industries that are looking for talented people. Thus we have in fairs an excellent device for insuring that scientifically minded youths have the opportunity to continue their education and to become the scientists of tomorrow.



The science fair gives a pupil recognition for his efforts, helping him to gain the respect of both adults and fellow pupils. He learns that society as a whole puts a premium on constructive activities.

DEVELOPMENT AND PRESENT STATUS OF FAIRS AND CONGRESSES

The growth of science fairs and congresses lies in the increasing popularity of the project method in science. In the 1920's a few of the larger communities carried on science fairs, the essential idea being for students to make exhibits showing the facts and principles as they were taught in science. About 1938, there developed a trend toward having a meeting place where pupils could come together to read

papers on their individual work, report their findings, and demonstrate their equipment. Thus we see the advent of a lecture-demonstration program apart from the simple exhibit of previous times.

One of the originators of the "congress" idea began with a chemistry club whose enthusiasm spread to neighboring communities and whose success then spread to the general public as participation was further encouraged. Impetus was added in 1938, when the American Institute of Science and Engineering Clubs established aids for young science students.

Today science fairs and congresses are conducted on a local, county, state and national scale. On the local level, we may find that a single school is having a science day or a school fair. The pupils who have made projects display these in the science rooms or in the school gymnasium. Residents of the community are invited to attend the affair. There is no formal judging by science experts. The teachers do the judging and the awards are simple—a certificate, a plaque, or merely a ribbon. The winners are sent to a local fair that may be city-wide or county-wide. On a county-wide basis, the competition is keener. The judges are not teachers but experts in the various fields of science, who had experience as judges before. They may be research scientists from industry or college professors. The awards may range from a trip through an industrial plant to a $50.00 bond.

A number of state teachers organizations have established regional fairs or congresses. These are usually one day affairs. The regional congress may involve a particular geographical area. In some cases as many as two hundred high schools are contacted. These schools are invited to enter competitive exhibits and demonstrations in this regional affair. The winners from these regional science fairs or congresses are invited to attend the state science congress, to compete for scholarships.

Each regional science congress has its own director and planning committee, which formulates the policies of the region. Usually the sponsoring body is an affiliate of the state science teachers association. In New York state, the Science Teachers Association sponsors the Annual State Science Congress. The association is interested in bringing together the outstanding high school scientists of the state. The participants must be in either the junior or senior year in high school. There are approximately twenty-five participants in the state congress each year. Each of the participants represents one of the regional congresses. Also on the state level, we find junior academies of science. These groups are sponsored by the respective state academy of science. Science fairs or science days are sponsored by the state organization,

at which time participants from districts in the state compete for awards.

The American Association for the Advancement of Science sponsors the Junior Scientists Assembly. Pupils who have proven to be outstanding in independent research are asked to attend the annual meeting of the organization, at which time they are brought before the total membership.

The Science Clubs of America sponsors the National Science Fair. The Science Clubs of America encourages the development and organization of science clubs on the local level. To encourage this activity, the National Science Fair was started in May 1950 at the Franklin Institute, Philadelphia. The thirty exhibits shown were the best produced by local science fairs.

The Science Clubs of America also conducts the Annual Science Talent Search in cooperation with the Westinghouse Company. Forty participants are selected on the basis of examination and projects from all parts of the country and are asked to attend the Science Talent Institute. The institute is a five day affair held in Washington during the spring of each year. The expenses of the participants are paid. In Washington, the participants compete for scholarships on the basis of a research project on which they report. Two hundred and sixty honorable mentions are also given to the pupils throughout the country who took the examination. Information concerning the Science Talent Search may be obtained from Science Clubs of America, Washington, D. C.

ORGANIZATION OF SCIENCE FAIRS AND CONGRESSES

The following [2] may serve as detailed information on the procedures to be followed in organizing and administering a science fair or congress:

Financing. It is essential that sufficient funds be forthcoming to cover all expenditures adequately. Such expenditures have varied from $200 to $2,500. Possible financing sources include newspapers, merchants, professional organizations, schools, theatrical and musical groups and others.

Sponsorship. Whether one or more sponsors should be secured will depend on many factors. There are many advantages to single as

[2] Prepared by J. Stanley Marshall, Professor of Science Education, Florida State University, Tallahassee, Fla.

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Factors in planning a fair or congress.

Area. The territory from which entries are to be accepted must be determined.

Date. The best time for holding the fair is as late in the school year as possible. Easter vacation is a recommended time.

Publicity. An announcement must be developed so that the students may be informed as to the many procedures to be followed. Community agencies will handle well-prepared releases. School art departments and school papers are able to assist, and the duplicating and printing can be done in the school departments. A central agency for publicity is recommended.

The fields of entry. The divisions for entries on elementary, junior and senior levels must be determined.

Printed material. Brochures, posters, entry blanks, registration cards, scoring cards, exhibition badge certificate of awards, and stationery are a few of the printed materials necessary.

Time element. At least three weeks to a month should be allowed for the receipt of entry blanks. One or two days should be set aside for arranging exhibits and one complete day for judging all exhibits.

Exhibit space. The layout of the space allotments in the exhibit rooms is very important. In planning exhibit space, the planning committee should consider the school cafeteria, gymnasium and the auditorium.

Pupils' part in planning science fairs. Many teachers permit their pupils to plan and execute a science fair as a student activity, as was done in a high school in Watertown, Massachusetts.[3] In this instance the teachers served as consultants only, while students managed the science fair. .Great emphasis was placed on securing a student leader whose qualifications included ability to work with people, intelligence, initiative, and administrative ability. A general operations committee was formed with an associate to assist and a faculty member serving as a consultant. The students used the Cambosco Scientific Supply Company brochure, "Methods of Conducting a Science Fair," as a guide for all operations. Suitable leaders as chairmen of the necessary sub-committees were immediately selected. Each chairman appointed members from the biology club and science classes and the first general pre-fair meeting was held. Faculty consultants attended this meeting at which time the history and philosophy of the science fair generally and locally were traced, the goals were set, limits and policies were established and responsibility and authority were defined. Following the initial meeting, four meetings were held by the general chairman

[3] MacCurdy, R. D., and Leacy, C. R., "A Science Fair Is Easy if You Let the Students Do It," *The Science Teacher*, February, 1954.

and the chairman of the sub-committees. All final policies were made by the general chairman and his associates. It was found an absolute necessity to have one recognized authority. The following committees were set up: committee on judges, financial committee, program committee and the committee on special arrangements.

Judging. MacCurdy and Bagshaw[4] have raised the issue of the reliability of judging at science fairs. They base their feelings on several facts. There are wide variations in project scores among many judges, the inconsistencies are so great that the winners have been established by methods that are open to serious criticism. An examination of the findings reveals that variations in judgments are so extensive that the judgments could not be called reliable or valid evaluations of the scientific qualities in the projects. Examination of the score cards used at one fair indicated that judges could be easily characterized as being high scoring, low scoring or medium scoring, and consistent or inconsistent in the scores they gave. It was deemed necessary to set up a revised score card, with more exacting and objective standards and narrower limits, constructed so as to help reduce inconsistencies, variations and poor judgments. MacCurdy and Bagshaw set out to devise a new card patterned after the U. S. Bureau of Dairying card used in judging cattle. This new card had all the basic features of the old card but those factors which had caused the widest variations were changed. The following are the main features of the new card. (The numbers represent the points assigned to each criterion.)

1. Scientific methods used in solving the problem (30)
2. Advancement in science for the contestant (20)
3. Ingenuity of construction, technical skill and workmanship (20)
4. Thoroughness (10)
5. Originality of concept (10)
6. Social implications (5)
7. The dramatic value (5)

Awards. Awards at science fairs and science congresses have included $10 and $50 bonds, donated by a local industrial concern, science books on various topics donated by publishers, and trips to industrial plants outside the community, sponsored by industry. Generally supplementing these awards are certificates or ribbons. On a larger scale, national science fairs and state congresses award full tuition or part tuition scholarships to various universities and colleges.

Awards given to winners on the local level are usually bonds, money, ribbons, certificates, books or small pieces of science equipment. Indus-

[4] MacCurdy, R. D., and Bagshaw, T. L., "Are Science Fair Judgments Fair?" *Science Education*, April, 1954.

trial concerns have the tendency to offer to schools bonds or money as awards. Such awards should be discouraged. Industry should donate money to support the fair in general but not in the form of bonds or money to be given as awards. In the estimation of many individuals who are experts in organizing science fairs, money and bonds more or less commercialize the fair and distract from its true meaning. Industry can certainly play a part in the fair by paying the expenses of the winners of a local fair for a trip to visit the research facilities of the concern located in another city. The General Electric Company, for example, provides such an opportunity to winners of local science fairs.

On the local level, it may be best to have a science day rather than a science fair, to avoid giving out extensive awards. If the affair concerns a single school, a science day is more appropriate. In such a case, the teachers in the school do the judging and awarding. The awards should be simple—perhaps just ribbons or certificates. The reasons for this are evident. A local fair may include 90 exhibits of which five are worth considering for competition on a regional level. The remaining eighty-five may be exhibits which the teacher forced the pupils to make. If competent judges are asked to make the awards, much of their time is wasted in evaluating a number of exhibits that are the work of pupils who were not interested in entering the fair in the first place.

In regional fairs, state congresses and national congresses, awards involving money should also be eliminated. Books, pieces of science equipment and other prizes which are connected with science are more meaningful to the boy or girl who is science-minded. These awards, along with certificates and ribbons, are treasured by these boys and girls in later years, and frequently serve as incentives for additional project work and individual study.

Scholarships awarded by universities, colleges, and industrial concerns are important awards. Universities and industries should be encouraged to continue this practice. These scholarships have given a number of boys and girls the opportunity to attend college. They may not have had this opportunity for further education without the scholarship award.

In summary, awards on the local level, in a single school, should be made by teachers and not outside judges, especially if the purpose of the local fair is to select participants for regional or district fairs. Awards on this level should be simple—certificates or ribbons. On the regional or state or national level, scholarships, field trips, books, and equipment are appropriate.

AN EXAMPLE OF A FAIR ON THE LOCAL LEVEL

The following description by Belle Cooper of an actual science fair illustrates in detail the functioning of a fair on the local level.

"The science fair was a definite project of the science club of North Fulton High School, a five-year community high school. With an enrollment of 1200 students, the school has approximately 460 students registered in some science class, with 240 more in eighth grade health classes. All members of the science club were expected to enter an exhibit. Exhibits from non-members were welcomed.

"There were six definite steps in organizing the fair: (1) planning, (2) publicity, (3) working up projects, (4) actual conduct of the fair, (5) judging and awards, (6) financing.

I. Planning. The dates for the fair were selected after a conference with science teachers, principal, and P.T.A. president and executive board. The opening date was chosen to coincide with a P.T.A. meeting so that parents might visit the fair before and after their evening program. This date was selected to avoid conflict with tests or examinations, and in order to allow time for students to add improvements to projects and enter them in the state science fair.

"Soon after the time was selected, the executive committee of the science club and the science teachers met to plan further. Each teacher and student volunteered for definite work, and other club members were invited to help. Committees were arranged for publicity, setting up exhibits, registering and protecting exhibits, judging, and awards. Each committee felt its responsibility and carried out its duties well.

II. Publicity. The publicity committee prepared and mimeographed a folder announcing fair dates, rules and regulations, and items to be considered in judging. The reverse side of the folder served as an exhibit entry blank. Suggestions for these items came from the Georgia State Fair and Science Service. On a given date, science club members appeared in every home class immediately after roll call, made oral announcements of the fair, delivered a mimeographer folder to each student, and answered questions.

"At least once a week, the president of the science club or a selected student made some ingenious announcement of the fair over the public address system. The *Scribbler*, the school newspaper, carried a prospectus of the fair, as well as a splendid article at the time of the fair. The art department made enough posters to keep the fair before the eyes of the students in both of our buildings.

III. Working up projects. With plans well laid and publicized, the students were ready for the important phase of preparing projects to exhibit.

"Each teacher used his own method for stimulating interest. Students were allowed to substitute a project for some required work, such as textbook study, reference work, or even a test. Some class time was allowed for work on projects; no additional homework was assigned.

"One method of arousing interest was to start with a class discussion of problems suggested by the students. Students were then sent out to read, experiment, and discuss subjects in which they were interested. This suggested lines of research, and they were on the mark ready to go. Several catalogs of suggested projects had been placed on reference in the library, and students drew ideas from these and other sources.

"There followed hours of work after school for science teachers, experimenting or planning with students, lending equipment, providing supplies, helping engineer the building of complicated apparatus, or suggesting authorities to interview. Interest, once aroused, was contagious, and students furnished all needed energy and ingenuity.

IV. Actual conduct of the fair. Four days before the fair, each exhibitor sent in his entrance blank with the entrance fee of ten cents. Besides aiding in the financing of the fair, this fee served to place greater value on the production by removing it from the "free" list. On opening day, on presenting his exhibit, each student received an exhibit card properly filled out, serially numbered, and colored across the corners with red, yellow, blue, or black paint, according to the subject area of his exhibit. The card used is approximately like that used in the national science fairs.

"The five subject areas were: biological sciences; physics and its applications; chemistry and its applications; other sciences; and social applications of science.

"Chemistry and physics laboratories with extra tables added served as exhibit halls, since they provided outlets for water, gas, and electricity. There were approximately 90 exhibits representing 130 students, including those working in groups.

"The fair was opened to visitors first at 7:30 in the evening. It remained open all the next day, and local students poured in to visit it during their study halls. It was also open to outsiders. A detail of guards and hosts was scheduled from study halls to be on duty each period of the day.

V. Awards. Judging took place as soon as exhibits had been placed, before the fair was opened to the public. Judges included two chair-

men of science departments from other community high schools and a doctor from the communicable disease center of the Public Health Service.

"Items considered in judging were the same as those used in national fairs:

1. Advancement of science
2. Social implications
3. Timeliness
4. Scientific thought
5. Originality
6. Dramatic value
7. Thoroughness
8. Ingenuity of construction
9. Technical skill and workmanship

"Any student who wished to demonstrate a working exhibit was allowed to do so before the judges. Judges were instructed to omit prizes in any area where there was no exhibit worthy of award. Ribbons were pinned to all prizewinning exhibits. In each subject area there was a first prize of \$4.30, a second prize of \$2.00 and an honorable mention. There was one over-all prize for the best ninth-grade exhibit.

VI. Financing. Financing the fair, strangely enough, was probably the easiest part. Since mimeograph paper was furnished by the school, and enough exhibit cards were left over from the 1951 fair, expenses were few."

Assets

Donation from school	\$20.00
From science club treasury (dues)	13.50
From exhibit registration fees	9.00
Total	\$42.50

Expenditures

Prizes	\$37.50
Supplies (thumb tacks, scotch tape, prize ribbons)	5.00
Total	\$42.50 [5]

STIMULATING PUPILS TO ENTER SCIENCE FAIRS

The chapter entitled "Projects in and out of school" suggests a number of devices which the teacher can use to motivate his pupils to do projects. Encouraging the students to work on projects is the

[5] Cooper, Belle, "The North Fulton Science Fair," *Selected Science Teaching Ideas of 1952*, National Science Teachers Association, Washington, 1952.

first step before the actual fair. Projects are an important activity and should be encouraged as part of classroom work and science club activity as well, but this does not mean that they should all be entered in a fair. Many science teachers have the idea that all projects should be included in a fair, local or regional, regardless of the caliber. As a result they force their pupils to work on projects to be entered in the fair by making the grade on the project part of the final grade.

Teachers should not force their pupils to enter projects in fairs; this practice defeats the purposes of the fair. It also discourages the pupils who would normally take more science to continue in science In addition, judges and other outside visitors receive a bad impression of the science taught in a particular school. It lowers standards of the fair and robs it of its real function.

There are ways, however, in which the teacher can stimulate voluntary participation:

1. In a school where science fairs are not established, pupils can be taken to schools where science fairs are being conducted.

2. Pupils who are doing projects can give a great deal of stimulation and encouragement to those who are not engaged in projects. Lecture-demonstrations during a regular class by these students may stimulate pupils to work on a project for science fairs.

3. A teacher should give recognition and praise to those who have done anything outstanding in the line of projects. Mention can be made that the project represents excellent work and that it is good enough to enter in a fair but pupils need not be forced to enter the fair, even though a project is good. The pupil should feel that it is an honor and a reward to enter the fair.

4. If the boy or girl is college material, the teacher should mention that the fair can be a good avenue to obtain a college scholarship.

5. Teachers should bring their pupils in contact with outstanding scientists. This can be done by inviting the scientist to school where he may suggest possible projects. Scientists in universities and in industry are interested in working with talented science pupils. Not only may they suggest projects to these talented people, but in some instances the scientists provide space and equipment at a university or a local industrial plant for these pupils, and even guide them in their research.

Suggested activities

1. Visit a science fair or congress with other members of your methods class. Obtain a judge's evaluation form at the fair. (This should be arranged by your method's teacher.) Independently evaluate

a pre-selected number of projects. Compare your evaluations with those of other members of your methods class.

2. Set up a science fair of the projects that you and the other members of your class made during the year. Provide these with labels that would interest non-scientifically trained people in the exhibits.

3. Cooperate in setting-up and conducting a local or regional science fair.

Suggested readings

Johnson, Philip G., "A High School Teacher's Opportunities for Guidance Towards Science," *Education*, March, 1953.

Jones, N. R. D., "Science Fairs—Science Education in the Community," *Science in Secondary Schools Today*, Bulletin of the National Association of Secondary School Principals, Volume 37, Number 191, January, 1953.

Science Clubs of America, *Science Club's Sponsor's Handbook*, Science Service, 1719 N Street N.W., Washington.

Science Clubs of America, *Sponsor's Handbook: Thousands of Science Projects*, Science Service, 1719 N Street N.W., Washington.

"Science Fairs," special issue of *The High School Journal*, Volume 39, Number 5, February, 1956.

PROPER SETTINGS FOR SCIENCE TEACHING

chapter 24

The evolution of science teaching in the last few decades has necessitated a parallel evolution in the physical settings—rooms and facilities—necessary for good instruction. As science teaching has become less concerned with presenting factual information as an end in itself, and more with using science to bring about important changes in ways of thinking and acting, the traditional room has become less functional.

From the room designer's viewpoint, one of the most significant trends has been the rapid increase in the number and variety of teaching methods. It has not been so very long since lecture-demonstration and stereotyped laboratory exercises were virtually the sole methods of instruction. Contrast this with the wide variety of activities in the modern classroom—project work, group discussion, pupil demonstration, film projection, the study of displays, to mention but a few. The modern room must be used for a film at the beginning of a period and a group discussion at the end; or for a test which is immediately followed by small group project work; or for several types of activities going on at the same time. Such a room must not only have the facilities for these activities but it must be converted easily and quickly from one purpose to another. Space and facilities must be designed with one important criterion in mind—flexibility.

THE DESIGN OF NEW FACILITIES

Room design is a complex task; in all probability no one person is capable of doing the whole job properly. Planning is best accomplished

by a committee of all people concerned. The committee should include school administrators, board of education members, representatives of the architect and contractor, and the science teachers who will use the rooms. In addition, the committee may well include other members of the community, not only for the services they might bring but also to increase community participation in school affairs.

The technical and advisory services of equipment and furniture manufacturers can be called upon. The W. M. Welch Company, for example, loans scale models of room furnishings for use in room layout and design. Other manufacturers, such as the Hamilton and Sheldon companies, maintain a planning service and can bring to the planning committee years of practical experience in designing and fitting modern science classrooms. (See appendix for addresses of supply houses.)

Site selection. Science is the subject most concerned with the outside environment. Whenever possible, the site of a new school should be chosen to provide suitable contacts with the world of science. A forested area, a pond, a stream, a hillside, become outdoor laboratories. A park near the school is a valuable asset. Sometimes through cooperation with a city planning commission, a school may be built near the site of a future park and certain natural features may be saved for educational purposes.

Location of science rooms. While school planning is still in the preliminary stages, some attention should be given to the location of the science rooms within the school. Biology and general science rooms, for example, should have southern or southeastern exposures to provide adequate sunlight for plants. To encourage field work, all science rooms should have either direct exit to the out-of-doors or should be close to main exits. Physical science rooms may be located near industrial arts classrooms so as to take better advantage of the facilities there.

Number of science rooms. The number of rooms required depends upon the type of program, the number of pupils, and, of course, the money available. The Richardson formula [1] may be used as a starting point:

$$\textit{Number of rooms} = \frac{\textit{Student-periods}}{\textit{Average class size} \times \textit{Periods per week}}$$

The number of *student-periods* is determined by multiplying the number of students by the number of periods that the classes meet in

[1] Richardson, John S., ed., *School Facilities for Science Instruction*, National Science Teacher's Association, Washington, 1954.

one week. The *periods per week* is the total number of periods per week that each room will be usable.

If the rooms required are one or less, an all-science classroom should be considered. If the sum is two or more, various combinations are possible.

Types of science rooms. Having decided upon the number of rooms required, the next step is determining the type of room. Science rooms may be classified as: (1) the all-science room in which all sciences are taught, (2) the semi-specialized room designed for instruction in a single area of science, such as the biological or physical science area, and (3) the specialized rooms for specific subjects such as chemistry and biology.

Room size. Modern science teaching, with its wide variety of activities and its need for "work centers" for independent activities, demands larger rooms than were formerly given to the lecture-demonstration type of program. As a general rule 35 to 40 square feet of floor space is needed for each pupil in the largest class that will use the room; this may be considered as adequate but not generous. In addition, 10 to 15 square feet per pupil, or about 20 percent of the total is useful as accessory space for larger projects and special activities.

General characteristics. The requirements for science classrooms are basically the same as those of conventional classrooms, with the addition of certain features peculiar to the needs of science instruction.

1. *Floors* receive a rugged and varied treatment. Chemicals and cold water damage many types of flooring; vinyl plastic makes a durable floor surface for science rooms.
2. *Ceiling* should be fireproof and paintable; acoustic materials are desirable.
3. *Walls* should also be fireproof and paintable; light colors brighten the room and make it more attractive; a white area on one wall makes a reasonable substitute for a projection screen.
4. *Lighting* is very important; illumination should be 35 to 40 foot candles for general work and higher in special work areas.
5. *Heating* should be sufficient to keep the room at a temperature of 68° F. with a relative humidity of 50 percent; special provisions are needed for keeping living things, as will be discussed later.
6. *Ventilation* should be adequate to carry away all odors produced by experiments and by organisms; in the chemistry room a fume hood is essential.

General work space. The ideal classroom has an area in which the pupils meet for such activities as recitations and demonstrations, and

other areas to which they are directed for experiments and project work. All this work space is flexible; seats may be reorganized for general discussions and for small group planning, and large areas of floor space may be cleared for special activities.

Within this ideal classroom there is also adequate desk, table, and workbench surface area for all activities. This flat work surface area is necessarily varied to meet the demands of the modern program and ranges from small surfaces on which to write notes to large tables on which major projects may be assembled.

The largest space investment in the science classroom is likely to be the student laboratory tables, and these units are also the most difficult to locate properly. These tables are inflexible by nature; their position cannot be varied, their surfaces, being broken up by utility services and sinks, provide little clear space, and their surfaces cannot be used for construction or other "rough" work.

Schools large enough to maintain several sections of each course often solve the problem by equipping separate laboratories and classrooms, scheduling one of the former to give laboratory facilities for three or four of the latter. Though efficient in terms of use, this is at the cost of good teaching. In the combined classroom laboratory a smooth transition from one activity to another is possible; problems arising from class discussion may be solved immediately by impromptu experiments, and experiments may be followed up immediately by films or reading.

Other schools have tried combining student laboratory and lecture positions, arranging the laboratory tables in rows facing the instructor. This practice provides such an inflexible classroom that good teaching becomes very difficult.

For a compromise that permits more efficient use of space than the ideal classroom, utility service may be provided along the walls with movable tables beneath. These tables may be used in this position when facilities are needed but they may also be pulled away from the wall and grouped in various ways.

It should also be remembered that for some courses such as general science and general biology, there is not much demand for tables equipped for all facilities. A few such tables may be put in these classrooms and different groups of pupils may carry out different activities at one time. Thus more classroom space becomes free for other uses.

Special work areas in the classroom. The teacher needs a small section for office space in which will be his desk, a filing cabinet, and one or two extra chairs for student conferences.

Special project work space is essential, preferably somewhat isolated

from the room by storage walls in which equipment and supplies can be kept. One of these work areas should be provided with a workbench and tools. To these work areas individuals or small groups may be sent to engage in independent projects.

Reading space is another "must." While it is not suggested that the science room assume the function of the school library, it is desirable at certain times for students to do reading and reference work in the classroom. This reading space should be equipped with a library table, chairs and bookcases, and a bulletin board.

Supplementary rooms. If a science classroom is to be in continual use by several different teachers, office space is needed outside the classroom for work on registers, planning, counseling and the like. One office may service two or three teachers but not more.

A darkroom has long been considered an essential *supplemental* room. This is usually equipped for photography but may well be used for certain types of experiments and for pupil project work

A growing room for plants and animals enables pupils to carry on projects in biological science work in a way not possible in the regular classroom. Some schools in the past have provided small greenhouses for their biology teachers but have ignored the general science teachers who need these facilities as much or even more.

Experience has shown that special rooms set aside for individual project work are of high value in helping talented pupils. In such rooms these pupils carry out projects both in school and after school, unhampered by the demands placed on the regular classroom. These rooms may be small but should be fully equipped with utilities and with ample locker space in which the pupils may keep materials.

Storage-preparation rooms are useful for any teacher and become essential when two or more teachers in separate classrooms must share the same materials. The ideal location for a storage-preparation room is between two classrooms, with an opening into each. It should also be accessible from the main corridor.

Furniture for science rooms. Each standard classroom should be equipped with a demonstration desk located in front of the space in which pupils sit. It should be of standing height, thirty-six inches from the floor. It should have full utility service: electricity, gas, hot and cold running water. The sink should be acid proof. Sometimes a compressed air supply is useful enough to justify the cost. There should be storage space for standard demonstration equipment. In crowded classrooms if there is no room for the teacher's desk, one or two locked drawers will be needed for records.

A cart of the same height as the demonstration table is useful to

transport materials to and from storage rooms, to set up demonstrations on, and even to use as a table on which to perform demonstrations. It should be made of stainless steel and have four large, rubber-tired wheels with locks. The top may have a surface matching that of the demonstration desk.

All science classrooms should be fully equipped with facilities necessary for pupils to carry out standard laboratory experiments. A number of types of laboratory desks are available; there are perimeter tables designed to fit along a wall, peninsula tables which project from the wall, and island tables which stand in the middle of the room. The latter are the easiest to supervise but reduce the amount of free floor space; they may be preferable for classrooms in which much standard laboratory work is carried out, such as in chemistry classrooms. The perimeter tables use the least amount of floor space but reduce other uses of the wall area, they may be preferred when only a few are needed, as in general science classrooms.

Student laboratory tables should be equipped with thick, acid-resistant tops—stone or specially treated wood. The sink should be of stone and the waste pipes of lead. It is useful to have two sets of electrical outlets—standard outlets for 110 volts D.C. and special outlets connected to a central control panel so that different voltages and frequencies may be supplied. There should be apparatus-support rods and sockets with each table. The type of storage space in each will vary with the courses being serviced.

A standard letter file is needed for clippings and pamphlets. A 3 x 5 inch card file having three or four drawers is needed for keeping inventories and for other records; this may be kept in a separate office if there is one.

A cabinet for charts and maps is required. These expensive items deserve good care. Neither they nor the appearance of the room is improved when they are rolled up and placed in a corner or on top of a wall cabinet.

A small, general purpose table, which may be of the folding type, will have many applications in the science room. It may be used for exhibits, displays, student conferences, project work and the like.

Special facilities. In addition to running water, gas, and electricity, which have been mentioned before and will be taken up again, science rooms need other special equipment and facilities. One wall should hold a large bulletin board for topical displays. A small bulletin board for current events clippings is also useful.

The front wall should have a well-lighted chalkboard. One section may be ruled off in squares to simplify the construction of graphs.

Several wall racks for charts and maps should be distributed about the room. One should be at the front of the demonstration area for the teacher's use during discussions; the others are for the pupils to use during individualized study.

The ideal projection screen is a built-in feature of the science classroom. Located near the front of the demonstration area where the pupils can view it without changing their seats, it becomes a regularly used tool. A stand for a projector, either fixed in place or movable, with an adjacent electrical outlet, is also needed. Dark shades are desirable. A darkened room is necessary when using an opaque projector. Many experiments and demonstrations call for a darkened room.

No science room should be considered equipped until it has a complete first aid kit and fire extinguishers. The first aid kit should contain neutralizing solutions, burn ointment, sodium bicarbonate, and surgical dressings. One fire extinguisher may be of the soda-acid type for general fires; the others should be for chemical and electrical fires.

Window shelves are very useful in general science and biology classrooms for plants and various vivaria. All too often this valuable space is wasted with radiators and vents. Even in physics and chemistry classrooms window shelves make excellent display areas and should not be neglected.

Equipment storage. Ordinary shelved storage cabinets are suitable for the storage of the majority of items of equipment. The problems in equipment storage are caused by the items of "difficult" size or shape: small items, long and tall ones. Special provision must be made for the storage of tall items such as Boyle's law apparatus, vertical resonance tubes and the like. Tall, narrow cabinets with cupboard type doors are available which will fill this need.

Drawer storage is suitable for long items such as Kundt's tubes and Liebig condensers, as well as small items. The storage cabinets purchased should have adequate drawer space. Partitions in drawers are seldom provided, although they are necessary for small-item storage, but they may be readily made from cardboard sheets; cardboard cartons used for shipping laboratory glassware such as beakers or flasks may be cut down and inserted in the drawers.

A rigorously logical system of equipment storage is difficult, owing to the varying sizes of the equipment. Where possible, items of a similar nature should be stored together; drawer storage may be alphabetical or topical. The most frequently used equipment should be stored in the most accessible places, and some equipment storage space that can be locked should be provided for fragile, expensive or dangerous equipment.

An equipment inventory is a vital part of the storage system. This inventory should be kept on 3 x 5 cards, stating the name of the item, quantity, condition, date purchased and the manufacturer. The location in the storage system should also be included.

Chemical storage. Chemicals are used frequently in all science courses, and their storage is extremely important. With the exception of chemicals which are purchased in large quantities, chemicals should be readily accessible; however, due to the potential, and in some cases extreme danger of chemical poisoning, some locked chemical storage space should be provided. Certain valuable chemicals also should be stored in a locked space.

Shelves in chemical storage cabinets should be surfaced with some resistant material. Owing to corrosion danger, particularly from hydrochloric acid fumes, metal equipment should be kept away from chemicals, in a separate cabinet or preferably in a different room. As a practical pointer, hydrochloric acid and ammonium hydroxide should be stored separately; the fumes react to form ammonium chloride which will collect on every available surface in the storage space.

Chemicals may be arranged in the cabinet alphabetically by element symbols, usually (in the case of compounds) the metallic element. In the case of compounds of a given metallic element they can be arranged in order of the non-metallic ion. It is sometimes convenient and space-saving as well, to separate bottles of liquids from jars of dry chemicals, and to separate larger containers from smaller ones.

An inventory should be kept of chemicals on 3 x 5 file cards, stating the name of the chemical, the quantity at time of inventory, and the date purchased. As the chemical is used, a notation may be made on the card and the item entered in the order book.

Storage for student purposes. Student laboratory stations should be provided with storage space for frequently used equipment. Drawers should be provided for glassware, burners, etc., while a locker is necessary for ringstands, clean-up equipment and the like.

There should be some provision made for the storage of student project work. Lack of such storage space is frequently a deterrent to effective project work, since projects are lost or broken by careless handling.

Storage furniture. Many types of storage furniture are available commercially. As in the case of the other types of classroom furniture discussed, the science-room planner should familiarize himself with these types before making any final decision.

Thought should be given to obtaining storage furniture which uses otherwise "dead" space in the classroom. The space between the top of the ordinary storage cabinets and the room's ceiling, for example, may be filled with cupboard type cabinets which may be used to store infrequently used items. Storage units may be built into partitioning walls between classrooms; these units have the advantage of accessibility from either side. Storage space may also be provided behind sliding tackboards and chalkboards. By the selection of proper furniture, almost any unused volume of space in the classroom may be adapted to storage purposes.

THE DESIGN OF SPECIFIC SCIENCE ROOMS

The problems of planning science rooms and facilities have already been dealt with in a general way. These problems are very similar from room to room, but each room presents one or more problems of its own. It will be the purpose of this section to discuss in detail the problems peculiar to each type of science room.

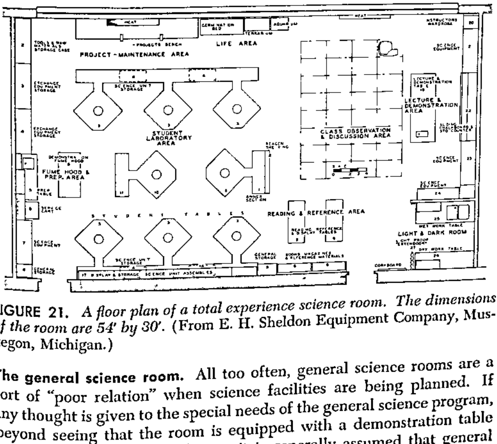

FIGURE 21. *A floor plan of a total experience science room. The dimensions of the room are 54′ by 30′.* (From E. H. Sheldon Equipment Company, Muskegon, Michigan.)

The general science room. All too often, general science rooms are a sort of "poor relation" when science facilities are being planned. If any thought is given to the special needs of the general science program, beyond seeing that the room is equipped with a demonstration table and one or two storage cabinets, it is generally assumed that general science is a sort of miniature version of biology, and consequently

the room in which it is taught may be a scaled-down replica of the biology room, less elaborately and expensively equipped.

This, of course, is not the case. Even fairly small schools will require a room devoted solely to general science to provide an adequate program, since general science is taken by more pupils than any of the other sciences. These rooms in their way are as specific in purpose as the senior science rooms; they have a distinct "personality" of their own. Their facilities should be as carefully designed for general science instruction, just as the physics rooms, for example, are designed for that subject.

General science, while it draws material from all fields of science, is not, or should not be, a "watered down" version of one or all of them; it is a science program in its own right with its own aims and values. Certain activity methods and instructional techniques are most suitable for general science, and efficient room design must take these into account.

General science activities are apt to include group discussion, committee work, project work, and all-class experimentation as well as demonstrations and use of audio-visual aids. Formal laboratory work of the traditional type is not necessary and may not be advisable. The laboratory work called for is simpler in nature and does not require the same amount or kind of furniture and equipment.

In smaller rooms that provide little work space around the room, flat-topped individual tables are best. These may be rearranged in various fashions to suit the nature of the activities being carried out. Several may be pushed together to provide large work surfaces. Tablet-arm chairs and slanted-top desks are not at all satisfactory. In a large room that provides additional work space, tablet-arm chairs may be used in the demonstration area.

In addition to these tables there should be one fully equipped laboratory unit of the physics or chemistry type, and another of the biology type. These may be along the wall or at the rear of the room. One or more additional sinks may be located at the rear or side of the room. There should be standard electrical outlets near all work surfaces.

Making and displaying projects is an important part of the general science program. Adequate tackboard space should be provided in readily visible portions of the room. Wall display cases are needed for collections and other exhibits. A display table was mentioned in a previous section. A combination sand table and display table has many uses.

Living materials form an important part of the general science course.

The general science room should have an aquarium, one or more terraria, animal cages and the like. A special project room may have facilities for growing plants also. These facilities are discussed more fully in the section on the biology room.

The storage problem in general science can be particularly vexing because the needs of the course are not anticipated. Since the course covers such a variety of topics, an equal variety of materials and equipment is needed. All of this must be stored carefully. Some of it must be locked up to keep it away from inquisitive and thoughtless pupils. In addition to cases in the classroom, a preparation-storage room with many additional cases is a necessity.

The biology classroom. Fundamental in the design of a biology classroom is provision for ready access to the out-of-doors and for bringing things found outdoors back inside for study. There should be adequate window space for plants and certain types of terrariums. There should be a few cages for animals brought in for temporary study.

A shelf should be provided for aquariums, with electrical outlets for aerators and heaters. Overhead lighting with fluorescent lamps adds to the attractiveness of the aquariums; this is to be preferred to sunlight, which promotes the growth of algae.

Special equipment that is to be desired for the study of living things include an incubator, a sterilizer, and a refrigerator. The first two may be moved from room to room as needed; the last named may be kept in a preparation room that is available to all.

Tables make the best work space for pupils; these may seat two or four pupils each. Tops should be acid resistant. There should be storage space for pupils' books and for frequently used materials. Electrical outlets will be needed if the pupils use microscopes a good deal. If microscopes are used only occasionally, pupils may work at side benches or move their tables to wall outlets. Without electric service the tables may be movable, to add to the flexibility of the room.

Gas, running water and electricity should be provided at one or two work centers, perhaps at standard laboratory tables. In addition, one or two large sinks are needed for washing equipment; these should have strainers that are easily removed, drainboards, and pegboards for drying glassware.

Display cabinets and tackboards are needed for exhibits. Models and specimens may be kept on permanent exhibit except when being used. Microscopes are best kept in locked-cabinets. A few other cabinets will take care of chemicals, glassware and miscellaneous supplies.

The growing room. The growing room is a valuable adjunct for biology and general science classrooms. In it may be kept living things that will be used for study in the regular classrooms. In it talented pupils may carry on special projects.

One growing room may service several classrooms. It should be near them but have separate entrances from the main corridor. A door to the outside is useful for bringing in or taking out bulk materials such as soil.

The growing room needs thermostatic temperature control and reasonable control of the humidity. There should be proper ventilation to take away odors. One end of the growing room should be fitted with a germinating bed, racks for garden flats, and storage bins for soil and fertilizer. Some large Wardian cases are needed for plants with high humidity requirements.

The shaded portion of the room should be equipped with shelves for aquariums, terrariums, and animal cages. Some dark closets are useful for keeping living things that avoid or do poorly in the light. In addition to the above, the growing room should have work space for potting plants and for cleaning animal cages. Running water and a sink should be available at this work center.

The physical science room. The physical science room may be planned specifically for chemistry or for physics, or it may be planned for joint use and for the physical science course now coming into favor. The requirements for all these courses are somewhat similar, differing only in emphasis, a physics room, for instance, may need more elaborate electrical facilities than does the chemistry room.

Laboratory tables should have chemical resistant tops, apparatus-support rods and sockets, gas, electricity, hot and cold water, and stone sinks with lead drains and traps. In a room specifically designed for chemistry, the advantages of stone tops should be weighed against the added cost, they may be more economical in the long run.

There should be easily accessible master valves for all gas and water services and a master switch for the electricity. A master breaker switch is needed to guard against overloads and it is well for each student desk to be similarly protected. It is helpful to have each student laboratory table equipped with a special outlet that is connected with an electrical control center. These outlets may then be serviced with electricity of different voltages and frequencies as needed.

Distilled water is used in large quantities. A wall still, permanently installed with its own water and waste connections, may be used, or an ion-exchange apparatus may be used. The latter is more expensive, but it is more convenient and produces purer water with one treatment.

The science darkroom. Photography is a valuable activity at all levels of science instruction, both as a subject for study in itself and as a valuable tool in instruction. For these reasons a darkroom makes a valuable addition to the science suite. The darkroom need not be large, but it should be accessible. If circumstances dictate that it be located in a specific room with no other access, the logical place for it is the physics room or the general physical science room.

Furniture for the darkroom should consist, at a minimum, of two benches, one equipped for wet work and one for dry. The dry table may be simply a folding classroom table, but the wet bench should be one of the type designed especially for photographic work, equipped with hot and cold running water, a flat space for developing trays and a large, stainless steel sink. Storage space for chemicals and at least one light-tight storage space for film and paper may be provided under the dry bench or in a wall storage cabinet.

A good quality of photographic work may be done with a surprisingly small amount of equipment. A start may be made with a quite simple set-up, and more complicated and expensive items of equipment added as funds become available. Beginning equipment should include some selection of the following items:

Development equipment. The necessary film tanks include roll film, sheet film, and 35 mm. day-load. If the darkroom is to be used for school photography purposes, such as yearbook photography, a 4 x 5 or 2¼ x 3¼ press-type camera will probably be used, and appropriate sheet-film tanks are necessary.

Trays should be break-resistant plastic or hard rubber. Enameled cooking pans may be used, but metal cooking pans are unsatisfactory, since they corrode and interfere with the action of the developer. 5 x 7 trays are probably the smallest suitable for use in a science darkroom, and one set of three 8 x 10 trays should be provided.

The following items of miscellaneous equipment are also needed for developing operations: a tank and tray thermometer, film clips for hanging films while drying (spring clothespins are good substitutes), a 1 quart and a 1 pint graduate (Pyrex measuring cups may be used instead), a stirring rod, brown bottles (1 pint, 1 quart, and 2 quart or gallon sizes for storing chemicals), a safelight (dark green for most modern films, amber for paper).

Printing equipment. A good contact box should be purchased. Contact printing frames are useful as instructional devices, but are not efficient darkroom tools. A reasonably good contact printer for negative sizes up to 5 x 7 can be obtained for around $15.

An enlarger is essential for quality photographic work. Good enlargers are expensive, and the less expensive enlargers lack ver-

satility. It is better to do without until funds are available to buy an expensive one than to buy a cheap enlarger. A possibility is to build your own enlarger. This is difficult, but feasible; perhaps the help of the shop teacher can be enlisted. The total cost of a home-built enlarger may be less than the cost of a cheap commercial one and can give better service.

IMPROVING EXISTING SITUATIONS

Very few teachers find themselves teaching in situations where they have designed all the facilities themselves. Most teachers will be teaching in rooms that they will find unsatisfactory to some degree. But good teaching can take place in spite of unsuitable conditions. Teachers should work constantly towards a betterment of these conditions.

The first step is an analysis of existing shortcomings as compared with ideal conditions. The second step is planning what may be done. The third step is setting a schedule of the order in which improvements may best be made. The fourth step is "action"—selling the plans to the administration and beginning such changes as lie within the teacher's powers.

Remodeling a classroom. Sometimes the school administration is willing to provide proper facilities in a room where none exists. Though this may be an expensive procedure, proper planning and wise purchasing will help hold costs down.

The orientation of the room—that is, the location of the demonstration table and the student tables, will depend upon the utilities. Sometimes the utilities may be tapped at the end walls, sometimes at the corridor walls, rarely at the outside wall. Sometimes they may be tapped through the floor to rooms or basements below.

For science courses that do not require extensive use of the utilities, one or two sinks may be located along walls containing water pipes, and gas and electricity may be supplied to wall tables only. Should utilities at pupil laboratory tables be essential, wall and peninsula type tables against the walls containing the piping represent the cheapest installation.

Electricity and gas can be supplied to wall tables with comparative ease. Pipes and electrical conduits can follow along the walls and be tapped where needed.

If no gas line exists in the school, bottled gas may be installed with small expense. It is even possible to use the small portable bottles for demonstration purposes, although these would be expensive for laboratory use by all pupils.

A fume hood, if needed, may be set up by a window with a blower to carry off the fumes. Perhaps a ventilating duct, if one exists in the walls of the room, can be tapped. The Kewaunee Manufacturing Company produces a portable fume hood which can be very useful in such a situation.

Aside from installation of the utilities, the remaining requirements for a good classroom should cost little more than for a new classroom. Some of the furniture might have to be built to special dimensions, but usually this is not necessary.

Minor room modifications. Many improvements can be made in a science room by rather minor changes. Imagination is needed. In one case, for example, an amazing increase in room flexibility was obtained through the simple process of exchanging the tablet arm chairs with which the room was equipped for the one-pupil tables in an English room. The increased flat space in a room previously deficient in working space permitted a great increase in the number of activities possible.

Room rearrangement can often lead to valuable results. For example, one of the first things a science teacher should do if the furniture in his room is fixed in position is to remove the screws and make the furniture movable, if its construction permits. Particularly in older classrooms, which were often larger than considered necessary by today's standards, enough space can be gained by rearranging to provide needed accessory space. For example, if six feet along one end of the room can be gained in this fashion, it may be partitioned off to provide useful, even if cramped, accessory space.

Much is to be gained from improving the appearance of a room; there is no need for the science room to be a dark, dreary place. The paint-roller has simplified painting to the extent that anyone with a roller and a free weekend can effect a complete change in the appearance of his room.

Many other room modifications will occur to the perceptive teacher. A science room is never so good that it needs no changes—or so bad that it must be abandoned as hopeless.

Constructing laboratory facilities. Construction skills of the teacher and the pupils may be put to good use as a source of needed furniture and equipment, particularly when funds are limited. In many cases, articles may be produced which are as good as commercially available counterparts at a fraction of the cost. Even where funds are not severely limited, construction by teachers and pupils provides a method for getting the most use of money and for getting articles specially designed for a particular situation. Such construction has

learning value as well, although it is not necessary to justify all such construction on the basis of learning value. Building a special-purpose table for the physics room may not contribute a great amount of direct experience in physics, but the table itself is a substantial achievement for the student.

Where funds are very limited, school construction sometimes becomes the only method of obtaining many needed articles. In this case, the wisest use of funds is investing in tools; with tools and a little ability to hunt up needed materials, limitations are imposed only by the skill and ingenuity of teachers and pupils. Without tools, very little is possible.

If the decision is made to begin an extensive school construction program, a few points should be considered. The first of these is to *insist on careful work.* The teacher who begins his construction program with the feeling that anything he can produce is just a poor substitute for "store-bought" materials is doomed from the start. The purpose of such a program will not be accomplished unless the items constructed are, within their limitations, as good as those available commercially. This does not mean they must be as elaborate or as finished in appearance; it does mean that they must be of equal utility. If the equipment constructed by pupils or teacher will not serve its intended purpose adequately, it is better to save what money is available until the needed articles can be purchased.

If the requisite care is taken, however, there is no reason why, over a period of years, the school construction program cannot provide the school with well-designed, useful equipment, in much greater quantity than would be possible if the same amount of money had been used for direct purchase.

A second rule is to *keep it simple.* Cleated joints in woodworking, for example, are not as good looking as dado or mortise-and-tenon joints; but they are as serviceable and more easily produced. Resist the temptation towards ornamentation, or towards tackling too elaborate projects, particularly in the beginning phases of the program. The reasons for this rule should be fairly evident; simplicity reduces costs and construction time. Pupils, as well as the teacher, are likely to tire of elaborate projects, with the result that the project remains in a corner somewhere unfinished, or else is finished off in a slap-dash fashion.

A third rule is to *design for solidity and utility.* Science room furniture and apparatus is likely to lead a rugged life. This should be kept in mind when plans are being made. If wooden construction is employed, be sure that the stock selected is of adequate size; better to err on the large size than on the small.

ORDERING AND MAINTAINING MATERIALS AND EQUIPMENT

The science teacher, in any situation, is responsible for ordering and maintaining science equipment. This means, that the teacher has to know what is on hand as well as the condition of the materials and equipment. From this point, the teacher can determine what has to be purchased—either to replace what has been used up or to replace equipment which has been damaged.

Determining the inventory. A teacher, in a new teaching situation, is confronted with the chore of determining the inventory of equipment, materials and supplies. If the new teacher is fortunate enough to have had a predecessor who was conscientious enough to keep a current record of materials the inventory creates no problem. Most teachers who arrive in new situations are not this fortunate.

A preliminary inventory accomplishes two purposes; not only does it inform the teacher of what is on hand, but it gives the teacher an opportunity to become familiar with apparatus that he has not come in contact with before.

Mr. James accepted a teaching position at Cherry Valley Central School. He was supposed to report to his new teaching position on September 4th. During the month of July, Mr. James decided to spend two or three days at the school to take an inventory of supplies and equipment. The preceding science teacher kept no records so Mr. James' job was overwhelming. The first thing he did was to inventory the chemical supplies. For each chemical he made out a 3 × 5 index card. On the card, he placed the name of the chemical and the amount on hand and also the date of the inventory. He also took an inventory of the apparatus and equipment and made out a 3 × 5 card on each piece. On each card he placed the name of the equipment, the purpose, its condition, the name of the equipment company that sold it, the date of the inventory and the place where it is stored so it could be readily located.

This was a monumental job, but when he finished he knew exactly what was available to teach his courses.

A card system to keep an up-to-date record of what is available may serve a number of purposes:

1. It is a ready reference file for supplies that have to be purchased.
2. Equipment can be located easily, since each card indicates the place of storage.
3. The annual inventory can be taken without difficulty.

Some school systems have purchasing departments which designate the company from which an item should be purchased. In such a case, the teacher should very clearly indicate in detail a description of the item so that the quality of the item is exactly as the teacher desires.

When to order materials and equipment. The science teacher should have a long range plan for ordering materials and equipment. Live material for example, should be ordered at a specified time during the year to assure its arrival when it is needed. Ordering live material during the summer months for use in the month of January is impractical unless it can be maintained during the summer months. The teacher should record the ordering date on the 3 × 5 inventory cards, so that he will be reminded to order such material enough in advance.

Expendable material has to be ordered yearly or each semester. During the summer months or before school closes, the teacher should indicate the needs to the principal or purchasing agent so that the material is available for fall. At this time, equipment which has been broken and has to be replaced should be ordered, together with new pieces of equipment that have never been part of the science inventory.

Maintaining science equipment. In order to make certain that equipment is in good repair, the science teacher should check it after use. Many pieces of equipment get out of adjustment after use by pupils and should be inspected when the pupils are finished using them.

A number of simple repairs can be done in the classroom if the science department is equipped with tools. It is not important to have elaborate tools, but certain basic tools are essential.

Shop tools for science teaching. Even if an extensive construction program of the sort outlined earlier in this chapter is not undertaken, the science department should have its own set of tools. It is not satisfactory to depend on the shop department except for occasional use of power tools; there is no assurance that the tools will be available when needed; and sending students to the shop every time tools are needed imposes an extra burden on the shop teacher.

Science projects cover such a wide area that a fairly comprehensive selection of tools is needed. Such tools may be divided into three categories: in the first are tools that represent the basic minimum; in the second group are tools that permit a wider variety of project work; in the third group are tools needed for elaborate projects. All tools should be of good quality. Cheap tools break easily, dull quickly, and are a handicap to good workmanship.

Good tools represent a large investment. They should be stored carefully in locked cabinets which show at a glance whether or not

items are missing. Tools left around have a way of disappearing; sometimes they are stolen, more often just borrowed and not returned. Not only is the financial loss serious but the loss of the tools handicaps the instructional program.

A few power tools are very useful. An electric hand drill has innumerable uses, especially if suitable accessories are provided. A power grinder permits tools to be serviced immediately without taking them to the industrial arts shops. Power saws, drill presses and lathes are luxuries if the school shops are available to the science teacher when he wishes to construct equipment or help pupils with projects, but sometimes they justify their cost.

Suggested activities

1. Suppose that the principal of your school has suggested that you use a standard classroom to provide for the science activities of a group of especially talented pupils. Plan the facilities you would like in this room for this purpose.
2. Assume that you are assigned a drab, dreary room for your science program. Develop plans for making this room an attractive place for young people to work.
3. Arrange a field trip to several new secondary schools in your area. Study the science facilities provided in each. Discuss among your classmates how the facilities in each school could be improved.

Suggested readings

Heiss, E. D., Obourn, E. S., and Hoffman, C. W., *Modern Science Teaching*, Macmillan, New York, 1950.

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CONTINUING TO GROW PROFESSIONALLY

chapter 25

A teacher should not consider himself a finished product when he completes his training and graduates from college. He should not be content to rely on what he has learned in his undergraduate work and strive only to improve his teaching skills and techniques. He must continue to grow professionally if he wants to increase his effectiveness as a teacher. In fact, he will become less effective as a teacher after a few years if he does not continue this growth. One of the principal reasons for this is the fact that our knowledge of science and its applications is increasing very rapidly. The growth of scientific research and new discoveries is proceeding at such a rapid pace that no one can know all the developments of science, even in any one particular field. A science teacher who wishes to do an adequate job must try to keep abreast of the developments of science which have important implications in his teaching.

Methods of teaching science are being continually improved. Research studies in methodology and educational psychology are providing knowledge which the teacher can use to improve his teaching. Teaching methods have been improved by research and through the development of materials to improve instruction. New and better apparatus is being developed for use in demonstrations and in laboratory work. A continual stream of new materials ranging from audio-visual aids to teacher's handbooks is being produced to help the teacher become more effective.

It is the responsibility of the individual teacher to keep himself in-

formed of the new developments, methods and materials which will make his teaching more significant and meaningful for his students.

GRADUATE STUDY

Many school systems require their teachers to take graduate work. In some instances these systems will pay the tuition for any course which will benefit the teacher in his teaching situation. In other school systems, a certain number of graduate credits will place a teacher in another step on the salary scale. In most states a master's degree or its equivalent is required for permanent certification in a subject matter area. These are all incentives for the teacher to take work which will improve him professionally. Teachers should not need these incentives to do graduate work. The beginning teacher and even an experienced one, no matter how well prepared, will soon see the need for more study to enrich his knowledge of science and to improve his teaching methods. The incentives mentioned should not be needed to encourage the competent teacher to better himself.

Graduate programs leading to a master's degree for science teachers vary considerably from university to university. A number of institutions have instituted general science programs which lead to a master of science degree in general science. In these programs, the teacher has an opportunity to extend his knowledge into areas, such as astronomy, genetics, and conservation, which were not included in his undergraduate work. One such program is given below:

Entomology	3 credits
Water biology	3 credits
Ornithology	3 credits
Field botany and ecology	3 credits
Heredity and evolution	3 credits
Descriptive astronomy	3 credits
Microbiology and man	3 credits
Earth materials	3 credits
Radiation biology	3 credits
General science comprehensive paper	3 credits
Total	30 credits

The same program may give the teacher a chance to concentrate in one or two science areas such as chemistry or physics to add to his depth of competence in these fields.

Some universities and colleges have programs for science teachers leading to a master of science in science education. In general these programs require 9 semester hours of courses in education, three semester hours in science education and 18 semester hours in science

content courses. These are well-balanced programs offered through the schools of education.

A well-balanced graduate program should include field courses as well as courses in bacteriology and microbiology. General science teachers need field work to be able to answer the variety of questions that arise in their classes. Biology teachers in particular should definitely include courses such as ornithology, entomology, water biology and field botany and ecology in their graduate programs to be able to enrich their biology courses and to be able to conduct field trips effectively. In addition, courses in microbiology and bacteriology are important since the advances in these areas have been so significant. Biology teachers should take these courses to realize that bacteriology is more than the bacteriology of disease.

At institutions where general science programs are offered, a research paper of one type or another is required to complete the degree. The paper is supervised by a professor in the field in which the paper is to be written. The following are titles of some research topics on which teachers have written while working on a master's degree in general science:

1. High polymer chemistry for beginning students.
2. The structure of the hereditary material.
3. Valence, its application to basic principles and reactions.
4. The genetics of some common cereal plants.
5. Historical development of leptons and nucleons.
6. The genetics of dogs.

In order to encourage science teachers to improve their professional competence, a number of programs for subsidized study have been established by industry and the government at various universities and colleges. The best known of these include summer and full-year institutes sponsored by the National Science Foundation. The General Electric Company has subsidized programs at various universities and colleges since 1945.

General Electric also offers summer study in the field of physics, chemistry, and mathematics. The General Electric Educational and Charitable Fund will give a science teacher a subsidy that includes tuition, room, board and travel. The National Science Foundation sponsors programs in all areas of science and mathematics, and teachers are subsidized to the extent of tuition, travel, books, subsistence and dependency allowances. During the academic year 1958-59, the National Science Foundation supported approximately 950 science teachers for a full year of study. During the summer of 1958, the National Science Foundation supported over 5000 science and mathematics teachers for six to eight weeks of study.

READING

Periodicals. There is such a vast amount of literature available that the science teacher has difficulty in selecting the material that would be most useful to him. There are, for example, many periodicals which can be read with profit. Some publish non-technical articles on science which can be utilized by all science teachers. These include such periodicals as *Scientific American, Popular Science, Science News Letter*, and *Science Digest*. Some popular magazines of general interest occasionally publish articles on science; *Life* is an outstanding example of this type.

There are a number of periodicals which the science teacher can read to broaden his understanding of the field of science teaching. Most of these are sponsored by professional organizations concerned with the teaching of science in the elementary and secondary schools. A list of these periodicals is given in the appendix.

Many state and local professional organizations publish magazines or bulletins on science teaching. For example, the Science Teachers Association of New York State issues *The Science Teachers Bulletin*.

A large number of professional scientific associations publish periodicals which report scientific advances and research findings. Many of these are quite technical in nature and would be of little use to the science teacher who does not have an adequate background. Some of the periodicals, however, are less technical in presentation and may have articles of interest to teachers of science in a particular subject field (see appendix).

Some universities publish bulletins and magazines which are of interest to science teachers. Probably the oldest and best known of these is the *Cornell Rural School Leaflet*. Some state organizations publish periodicals which can be used in teaching science. A good example of this is the *New York State Conservationist* issued by the State of New York Conservation Department, and *Arizona Highways*, issued by the Arizona Highway Department.

Books. There are a great number of books published each year in the field of science. College textbooks are a good source of information for the science teacher who wants to broaden his knowledge of a particular subject. Each year many books on science are published. The science teacher can turn to the book reviews in such magazines as *Nature Magazine, Science News Letter, The Science Teacher, Scientific American*, and *Scientific Monthly* for help in selecting books to read or to purchase. Many good books on all phases of science are available in inexpensive paperbound editions which make a valuable addition to the personal library of the science teacher.

nish material about which to write. By writing about his own classroom the teacher can analyze his teaching methods and try to improve them. The science teacher can describe effective techniques and teaching aids which he has developed; these are of interest to science teachers in general.

If the science teacher has made experimental studies or has developed new ideas to improve teaching methods or revised the science curriculum, these should be reported, for they are of interest to other teachers and administrators.

The teacher's writing can be of interest to many different types of individuals. The pupils and parents will be interested in matters pertaining to student activities in the local classrooms. The school and local newspapers publish articles on these topics. Professional bulletins and journals at the local, state, and national level provide the means for the teacher to publish articles of interest and concern to the profession as a whole.

Articles written by science teachers can be submitted to the editors of various professional journals in the field of science teaching. The names of the editors can be found in each copy of these journals. In preparing an article for publication, various journals have certain specified formats to follow. For example, most journals require that the article be submitted on 8 × 10 paper, typewritten and double spaced. In some cases, the editors state that photographs should not be dispersed throughout the article but all placed on one page, properly numbered and with the captions on the bottom of the page. They may also require that the photographs occupy a certain area on the page so that the page can be more easily reproduced. The journals may also limit the number of photographs. Usually additional photographs can be incorporated beyond a specified number as long as the author assumes the expense. If a single photograph is to be submitted along with the article, it should be 8 × 10 in size and of exceptional quality.

In general, diagrams and line drawings should be drawn in India ink. They should be clear and properly labeled. Pencil drawings are not accepted unless the journal provides an artist to draw the diagram for the author. This usually is not the case.

OTHER MEANS OF PROFESSIONAL GROWTH

Contacts with other teachers. A beginning science teacher finds that other teachers are one of his most valuable sources of information and inspiration. Another science teacher can be especially helpful in selecting objectives, methods, materials and sources of information. Even the well-qualified teacher finds his fellow teachers to be im-

portant resources in his professional growth. By working with other teachers who are not in the field of science teaching the science teacher learns to see the relationships of his subject with other subjects. This may bring about a better correlation between subjects and improve the instruction in the school.

The science teacher can grow professionally by his contacts with teachers in other schools during visitations, conferences or meetings. The teacher can broaden his outlook on teaching methods and philosophies by the perspective gained through these wider contacts. The importance of visiting other science teachers in another school within the district or outside of the district cannot be over stressed. Beginning teachers should see experienced science teachers in action. Whenever a science teacher is known to be outstanding, he should be observed insofar as possible by the inexperienced.

In-service education and workshops. A valuable method of teacher growth is by means of purposeful and well-conducted in-service meetings and workshops. Meetings to improve the curriculum or to solve problems of importance to the participants will provide an invaluable means of sharing thoughts on methods, activities, resources and the scope and sequence of courses. Working together cooperatively can benefit all the participants and help to improve the quality of instruction in the school.

Along with the workshop idea, many communities have cooperated with industry by setting up visiting days in various industrial plants in the area. The school systems permit teachers to visit these industrial plants on a particular day. All classes are cancelled for one day in the entire district and teachers visit one or two plants within the area. Teachers learn how science and technology are related. They can see and learn how certain scientific principles have been used in an industrial process. This experience in turn, enriches the science curriculum in the classroom of the teacher who has had the experience.

Travel. The science teacher can use travel not only to provide relaxation and pleasure, but also to gather much information, experience and material that will help him to improve his teaching. A camera, preferably 35 millimeter, can be used to take photographs for use in the classroom. Advanced planning is needed to obtain the greatest benefit from travel. Tourist bureaus, chambers of commerce and travel agencies can provide information and literature about the places to be visited. Visits to other places in the United States provide a great opportunity to collect plant and animal specimens for biology teaching. Animals and plants can be studied in their natural habitats. Visits to museums can give a teacher many new ideas concerning exhibits and

collections. Visits to local industries and spots of scientific interest can be utilized fully by taking photographs, obtaining samples and collecting descriptive literature. A science teacher can acquire a great deal of information and material for his classroom without detracting from the enjoyment of his travels.

Summer employment. Industry in some instances has helped science teachers grow professionally by providing science related summer jobs. These enable the teacher to gain an understanding of the applications of science in industry. The teacher may work in a laboratory where he will develop skills and understandings in the methods of research which will be used in the school to improve instruction.

Some universities have established a practice of hiring teachers as research assistants through the summer months. As assistants, the teachers can help on routine operations until they develop the skill and knowledge to do more advanced work. In many cases, the teachers take courses at the university while working. In this manner the teacher not only acquires up-to-date knowledge and methods, but also develops skills and attitudes toward research that he will carry back to the classroom and laboratory to stimulate his students.

Science hobbies. Teachers can enrich their curriculum by having science hobbies that may be directly or indirectly associated with their teaching area. For example, many science teachers are ardent entomologists or ornithologists. Many are excellent water biologists. It is not uncommon to find a chemistry teacher who is an enthusiastic bird watcher or a biology teacher who is an excellent geologist. Hobbies not only help to enrich the curricula, but they stimulate pupils to do projects if they see teachers who are actively interested in their own hobbies.

Research. Many science teachers have excellent backgrounds in a particular science area. Some have advanced degrees in these science areas, a fact that means that they have the necessary background to do research. Teachers with extensive backgrounds in an area of science should be engaged in research. Teachers who feel that they do not have the space, the equipment or the materials to do research should solicit the help of a near-by university. University professors will generally cooperate with teachers on a research project by providing space and equipment. Teachers should not neglect to use this source of aid.

Pupils who know that teachers are actively engaged in a research project may be stimulated to work on projects of their own. If the teacher reports his findings to the pupils, he may find that many of

the exceptional pupils may be interested in helping him on the project.

High school teachers who publish their research in recognized journals receive the recognition from their colleagues as well as their pupils. These teachers will be regarded as specialists and authorities in their science area. Members of the community will also recognize them as outstanding teachers and scientists. They will be recognized as the teachers under whom parents would like their children to study.

Suggested activities

1. List the books and periodicals that should be found in a science teacher's professional library.
2. Obtain a copy of "Star Ideas in Science Teaching," published by the National Science Teachers Association. Discuss why these techniques were chosen as being outstanding.
3. Join the National Science Teachers Association and your state science teachers' organization. If possible, attend some of their conventions.

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Reipiers, James, "Basic Science and the Student," *School of Science and Mathematics*, April, 1951, page 289.

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APPENDIX

Sections A through H of the appendix include lists of books and printed materials that may be useful to science teachers, both in the science library, for the pupils' use, and in the teacher's own library, for teaching suggestions and professional aids. Sections I through L give sources of science equipment, supplies, and furniture for the secondary science program.

A. REFERENCE BOOKS FOR THE SCIENCE LIBRARY

Bennett, H., *Chemical Formulary*, Van Nostrand.[1] (Gives detailed directions for making thousands of various chemical products.)

Bernhardt, *New Handbook of the Heavens*, Mentor and Signet Key Books, The New American Library of World Literature, Inc., 501 Madison Avenue, New York 22, N. Y.

The Book of Popular Science, The Grolier Society, Inc., 2 West 45th St., New York, 36, N. Y. (Ten volumes concerning all junior and senior high school sciences, continuous revision plan.)

Himes, G. H., *Dictionary of Geology*, Penguin.

Hodgeman, Charles, ed., *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., 2310 Superior Ave., N. E., Cleveland, Ohio.

Johnson and Abercrombie, *Dictionary of Biology*, Penguin.

Lange, Norbert, ed., *Handbook of Chemistry*, Handbook Publishers, Inc., Sandusky, Ohio.

Pictured-Key Nature Series, William Brown Co., Dubuque, Iowa. (This series consists of several separate spirally bound inexpensive volumes on many specific

[1] Addresses of publishers not given here are listed in section G.

biological subjects including: fresh-water algae, grasses, immature insects, fall flowers, trees, protozoa, beetles, insects, land birds, spiders, and mammals.)
Uvarov, E. B., *Dictionary of Science*, Penguin.
Van Nostrand's Chemists Dictionary, Van Nostrand.
Van Nostrand's Scientific Encyclopedia, Van Nostrand.

B. GENERAL BOOKS FOR THE SCIENCE LIBRARY, BY SUBJECT

Airplanes, rockets and space ships

Bendick, J., *The First Book of Space Travel*, Watts, 1954.
Chapel, C. F., *Jet Aircraft Simplified*, Aero Publishers, Inc., 2162 Sunset Blvd., Los Angeles, 1950.
Clarke, Arthur C., *Going into Space: An Introduction to Interplanetary Travel*, Harper, 1954.
Coggins, Jack and Pratt, Fletcher, *Rockets, Jets, Guided Missiles and Space Ships*, Random House, 1951.
Floherty, J. J., *Aviation from the Ground Up*, Lippincott, 1950.
Grant, Charles H., *Model Airplane Design and Theory of Flight*, Air Age, 1941.
Lewellen, J., *Birds and Planes: How They Fly*, Crowell, 1953.
———, *You and Space Travel*, Childrens Press, 1951.
Ley, Willy, *Rockets and Space Travel*, Viking, 1954.
Leyson, Burr W., *Man, Rockets and Space*, Dutton, 1954.
McClintock, Marshall, *Airplanes and How They Fly*, Stokes, 1943.
Neurath, Marie, *Rockets and Jets*, Lothrop, 1952.
———, *Speeding into Space*, Lothrop, 1954.
Ross, Frank, Jr., *Flying Windmills: The Story of the Helicopter*, Lothrop, 1953.
———, *Guided Missiles, Rockets and Torpedoes*, Lothrop, 1951.
———, *Young People's Book of Jet Propulsion*, Lothrop, 1951.
Yates, F. R., *Boy's Book of Rockets*, Harper, 1947.
———, *Model Jets and Rockets for Boys*, Harper, 1952.
Zim, H. S., *Rockets and Jets*, Harcourt, 1945.

Animals

Andrews, Roy C., *All About Whales*, Random House, 1954.
———, *Nature's Way: How Nature Takes Care of its Own*, Crown, 1951.
Bridges, William, *Wild Animals of the World*, Garden City Books, 1948.
———, *Zoo Expeditions*, Morrow, 1954.
Brown, W. S., *Turtles*, Harcourt, 1945.
Buck, Frank, and Fraser, F. J., *Jungle Animals*, Random House, 1945.
Clark, A. H., *Animals Alive*, Van Nostrand, 1946.
Ditmers, R. L., *Strange Animals I Have Known*, Harcourt, 1931.
Earle, Olive L., *Paws, Hoofs and Flippers*, Morrow, 1954.
Fenton, C. L., *Wild Folk at the Pond*, Day, 1948.
Greenberg, S. S., and Rasken, E. L., *Homemade Zoo*, McKay, 1952.
Hausman, L. A., *Beginner's Guide to Seashore Life*, Putnam, 1949.
———, *Beginner's Guide to Fresh Water Life*, Putnam, 1950.
Henderson, L. M., *Amik, the Life Story of a Beaver*, Morrow, 1948.
Hogner, D. C., *Animal Book: American Mammals North of Mexico*, Oxford, 1942.

Innes, W. T., *Modern Aquarium,* 20th ed., Innes, 1952.
——, *Your Aquarium,* 9th ed., Innes, 1950.
Kane, H. B., *Wild World Tales,* Knopf, 1949.
Leyson, Burr W., *The Zoo Comes to You,* Dutton, 1954.
Mason, G. F., *Animal Homes,* Morrow, 1947.
——, *Animal Sounds,* Morrow, 1951.
——, *Animal Tools,* Morrow, 1951.
——, *Animal Tracks,* Morrow, 1943.
——, *Animal Weapons,* Morrow, 1949.
McClung, Robert M., *Bufo: The Story of a Toad,* Morrow, 1954.
——, *Stripe: The Story of a Chipmunk,* Morrow, 1951.
McMeekan, I. M., *The First Book of Horses,* Watts, 1949.
Mellen, I. M., *Wonder World of Fishes,* Dodd, 1951.
Milne, L. J. and Milne, M. J., *A Multitude of Living Things,* Dodd, 1947.
Ripper, Charles L., *Bats,* Morrow, 1954.
Robertson, G. V., and Graham, V. M., *Strange Sea Life,* Holt, 1950.
Sears, Paul M., *Tree Frogs,* Holiday House, New York, 1954.
VonHagen, V. W., *South American Zoo,* Messner, New York, 1946.
Zim, H. S., *Elephants,* Morrow, 1946.
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——, *Goldfish,* Morrow, 1947.
——, *Mice, Men and Elephants: A Book About the Mammals,* Harcourt, 1942.
——, *Snakes,* Morrow, 1949.
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Astronomy

Barton, W. H., and Joseph, J. M., *Starcraft,* 2nd rev. ed., McGraw-Hill, 1946.
Brindze, Ruth, *The Story of Our Calendar,* Vanguard, 1949.
Cothren, M. B., *This Is the Moon,* Coward-McCann, New York, 1946.
Dunham, M. P., *What's in the Sky?* Oxford, 1941.
Fenton, C. L., and Fenton, M. A., *Worlds in the Sky,* Day, 1950.
Gamov, George, *The Moon,* Schuman, New York, 1953.
Hickey, J. C., *Introducing the Universe,* Dodd, 1951.
Johnson, Gaylord, rev. by Irving Adler, *Discover the Universe,* Sentinel, New York, 1954.
Lewellen, J., *You and Space Neighbors,* Childrens Press, 1953.
Lum, Peter, *Stars in Our Heavens: Myths and Fables,* Pantheon, 1948.
Meyer, J. S., *Picture Book of Astronomy,* Lothrop, 1945.
Parker, B. W., *Beyond the Solar System,* Harper, 1941.
Reed, W. M., *Patterns in the Sky: The Story of the Constellations,* Morrow, 1951.
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Rey, H. A., *The Stars: A New Way to See Them,* Houghton Mifflin, 1952.
Schneider, H., and Schneider, M., *You Among the Stars,* Scott, 1951.
Skilling, W. T., and Richardson, R. S., *Sun, Moon and Stars: Astronomy for Beginners,* McGraw-Hill, 1946.
Spitz, A. W., *The Pinpoint Planetarium,* Holt, 1942.
White, Anne T., *All About the Stars,* Random House, 1954.
Williams, Lou, *Dipper Full of Stars: A Beginner's Guide to the Heavens,* rev. and enl. ed., Wilcox, 1950.
Wyler, Rose, *Planet Earth,* Schuman, New York, 1952.

Wylie, C. C., *Our Starland: An Easy Guide to the Study of the Heavens*, Lyons, Carnahan, 2500 Prairie Ave., Chicago, 1949.

Birds

Bronson, W. S., *Starlings*, Harcourt, 1948.
Hausman, L A., *Field Guide for Birds, Wild Flowers, and Nature Study*, Grosset, 1948.
Hickey, J. J., *A Guide to Bird Watching*, Garden City Books, 1953.
Kieran, John, *Introduction to Birds*, Garden City Books, 1950.
Peterson, A. M., *Wild Bird Neighbors*, Wilcox, 1947.
Peterson, R. T., *Field Guide to the Birds*, 2nd rev. and enl. ed., Houghton Mifflin, 1947.
———, *How to Know the Birds*, Houghton Mifflin, 1949.
Pettie, T. S., *Birds in Your Back Yard*, Harper, 1949.
Zim, H. S , and Gabrielson, I. N., *Birds: A Guide to the Most Familiar American Birds*, Simon and Schuster, 1949.
———, *Homing Pigeons*, Morrow, 1949.

Earth sciences: anthropology, conservation, geology, paleontology, weather

Andrews, Roy C., *All About Dinosaurs*, Random House, 1953.
———, *Meet Your Ancestors*, Viking, 1945.
Bates, Marston, *Where Winter Never Comes: A Study of Man and Nature in the Tropics*, Scribner, 1952.
Bronson, Wilfrid S , *Freedom and Plenty: Ours to Save*, Harcourt, 1943.
Carpenter, Shirley, and Neurath, M., *Icebergs and Jungles*, Hanover House, New York, 1945.
Carpenter, Shirley, Neurath, M., and Irwin, S., *Mountains and Valleys*, Hanover House, 1954.
Carson, Rachel, *The Sea Around Us*, Oxford, 1951.
Clark, G , *From Savagery to Civilization*, Schuman, New York, 1953.
Cormack, Maribelle, *First Book of Stones*, Watts, 1950.
Dickinson, Alice, *The First Book of Prehistoric Animals*, Watts, 1954.
Epstein, S., and Williams, B., *The Real Book About the Sea*, Garden City Books, 1954.
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Graham, E. H., and Van Dersal, W. R., *Wildlife for America: The Story of Wildlife Conservation*, Oxford, 1949.
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Knight, Charles R., *Before the Dawn of History*, McGraw-Hill, 1935.
Lane, Ferdinand, C., *All About the Sea*, Random House, 1953.
Longstreth, T. M., *Knowing the Weather*, Macmillan, 1943.
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Novikoff, A. B., *Climbing Our Family Tree*, International Universities Press, New York, 1945.
Pough, Frederick H., *All About Volcanoes and Earthquakes*, Random House, 1953
Reed, W. M., *The Earth for Sam*, Harcourt, 1941.
Sloane, Eric, *Clouds, Air and Wind*, Devin-Adair, New York, 1941.
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Williams, H. L., *Stories in Rocks*, Holt, 1948.
Wyler, R., and Ames, G., *Life on the Earth*, Schuman, New York, 1943.
Zim, H. S., and Cooper, E. K., *Minerals: Their Identification, Uses and How to Collect Them*, Harcourt, 1943.

General science, including physics and chemistry

Adler, Irving, *The Secret of Light*, International Universities Press, New York, 1952.
Asimov, Isaac, *Inside the Atom*, Abelard-Schuman, New York, 1956.
Bechdolt, J. E., *Going Up: The Story of Vertical Transportation*, Abingdon-Cokesbury, 1948.
Bendick, Jeanne, *All Around You: A First Look at the World*, McGraw-Hill, 1951.
Bibby, Cyril, *How Life Is Handed on*, Emerson Books, New York, 1947.
Billings, Henry, *Man Under Water*, Viking, 1954.
Block, Marie H., *Tunnels*, Coward-McCann, New York, 1954.
Buehr, Walter, *Through the Locks: Canals, Today and Yesterday*, Putnam, 1954.
Clarke, James, *Picture of Health*, Macmillan, 1940.
Floherty, J. J., *Five Alarm: The Story of Fire Fighting*, Lippincott, 1949.
———, *Watch Your Step*, Lippincott, 1950.
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Freeman, Ira M., *All About the Wonders of Chemistry*, Random House, 1954.
Gould, J., *All About Radio and Television*, Random House, 1953.
Hoke, John, *The First Book of Photography*, Watts, 1954.
Holton, G. J., *Story of Sound*, Harcourt, 1948.
Ley, Willy, *Dragons in Amber*, Viking, 1951.
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Lineaweaver, M., *The First Book of Sailing*, Watts, 1953.
Meyer, J. S., *Picture Book of Chemistry*, Lothrop, 1950.
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Poole, Lynn, *Science, the Super Sleuth*, Whittlesey House, New York, 1954.
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Riedman, S. R., *How Man Discovered His Body*, International Universities Press, New York, 1947.

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Ross, Frank Jr., *Radar and Other Electronic Inventions*, Lothrop, 1954.
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Schwartz, Julius, *Little Things That Make a Big Difference*, Whittlesey House, New York, 1954.
Selsam, M. E., *Microbes at Work*, Morrow, 1953.
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Somerville, J., *The Way of Science: Its Growth and Method*, Schuman, New York, 1953.
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Yates, R. F., *Fun with Your Microscope*, Appleton-Century-Crofts, 1943.

"How to" books: experiments, construction and explanation

Baer, M. E., *Without Fire: A Book of Experiments*, Rinehart, New York, 1946.
Beller, N. F., and Branley, F. M., *Experiments with Electricity*, Crowell, 1949.
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Britton, Katherine, *What Makes It Tick?* Houghton Mifflin, 1943.
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———, *Pet Book for Boys and Girls*, Scribner, 1949.
———, *Simple Chemical Experiments*, McGraw-Hill, 1948.
———, *The Boy Electrician*, rev. ed., Lothrop, 1948.
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Peet, Creighton, *How Things Work*, Holt, 1941.
Schneider, H., *Everyday Machines and How They Work*, McGraw-Hill, 1950.
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Simmons, M. P., *The Young Scientist, Activities for Junior High School Students*, Exposition, New York, 1951.
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Verrill, A. H., *Young Collector's Handbook*, McBride, New York, 1948.
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Bronson, W. S., *The Grasshopper Book*, Harcourt, 1943.
Harpster, H. T., *Insect World*, Viking, 1947.
Lane, Ferdinand C., *All About the Insect World*, Random House, 1954.
Lutz, F. E., *A Lot of Insects*, Putnam, 1941.
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Neurath, M., *The Wonder World of Insects*, Lothrop, 1953.
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Williamson, Margaret, *First Book of Bugs*, Watts, 1949.
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Brown, Vinson, *The Amateur Naturalist's Handbook*, Little, Brown, Boston, 1948.
Buck, M. W., *In Woods and Fields*, Abingdon-Cokesbury, 1950.
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Hillcourt, William, *Field Book of Nature Activities*, Putnam, 1950.
Hylander, C. J., *Out of Doors in Autumn*, Macmillan, 1942.
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Pettit, Ted, *Book of Nature Hobbies*, Didier, New York, 1947.

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Blough, Glenn O., *Wait for the Sunshine: The Story of Seasons and Growing Things*, McGraw-Hill, 1954.
Collingwood, G. H., *Knowing Your Trees*, 5th ed., American Forestry Association, 1941.
Cormack, Maribelle, *The First Book of Trees*, Watts, 1951.
Cosgrove, M., *Wonders of the Tree World*, Dodd, 1953.
DuPuy, W. A., *This Living World: Our Plant Friends and Foes*, 3rd ed., Winston, Philadelphia, 1948.
Ellis, Carleton, and Swaney, M. W., *Soilless Growth of Plants*, 2nd ed., rev. and enl., Reinhold, New York, 1947.
Lucas, J. M., *First the Flower, Then the Fruit*, Lippincott, 1943.
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———, *Indian Harvest: The Wild Food Plants of America*, Lippincott, 1945.
McKenny, Margaret, *Trees of the Countryside*, Knopf, 1942.
Moore, Alma C., *Friendly Forests*, Viking, 1954.
Rogers, Matilda, *First Book of Tree Identification*, Random House, 1951.
Schneider, H., and Schneider, N., *Plants in the City*, Day, 1951.
Sterling, D., *Trees and Their Story*, Doubleday, 1953.
United States Department of Agriculture, *Yearbook of Agriculture: Trees*, 1949.
Zim, H. S., *Plants: A Guide to Plant Hobbies*, Harcourt, 1951.
Zim, H. S., and Martin, A. C., *Flowers: A Guide to 260 Familiar American Wildflowers*, Simon and Schuster, 1950.

C. SUGGESTED PERIODICALS FOR THE SCIENCE LIBRARY

Aquarium
Audubon Magazine
Consumer Reports
Field and Stream
Flying
Life
Mechanics Illustrated
National Geographic Magazine
Popular Mechanics
Popular Photography
Popular Science
Radio Electronics
Science Digest
Science World
Sky and Telescope

D. PROFESSIONAL SCIENCE EDUCATION BOOKS

Aiken, W. M., *The Story of the Eight Year Study*, Harper, 1942.
Baker, John R., *Science and the Planned State*, Macmillan, 1945.
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Science Clubs of America, *Sponsors' Handbook: Thousands of Science Projects,* Science Service, 1719 N St. N. W. Washington 6, D. C.
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E. PROFESSIONAL JOURNALS, MAGAZINES AND PAMPHLETS

Journals and magazines

American Biology Teacher, National Association of Biology Teachers, Bryan, Ohio.
American Journal of Physics, American Institute of Physics, 335 E. 45 St., New York, 17.
American Scientist, Sigma Xi, 54 Hillhouse Ave., New Haven 11, Conn.
Canadian Nature, Audubon Society of Canada, 181 Jarvis St., Toronto 2, Ontario.
Chemical and Engineering News, American Chemical Society, 1155 16 St. N. W., Washington, D. C.
Cornell Rural School Leaflets, N. Y. State College of Agriculture, Cornell University, Ithaca, N. Y.
Journal of Chemical Education, 20 & Northampton Sts., Easton, Pa.
Look and Listen, Britain's Audio-Visual Aids Journal, 62 Doughty St., London, W. C. 1.
Mathematics Teacher, National Council of Teachers of Mathematics, 1201 16 St. N. W., Washington.
National Geographic, National Geographic Society, 16 and M St., N. W., Washington 6.
Natural History, American Museum of Natural History, Central Park W. and 79 St., New York.
Nature, Macmillan Co., St. Martin's St., London, W. C. 2.

Review of Educational Research, American Educational Research Association, 1201 16 St. N. W., Washington.
School Science and Mathematics, Box 408, Oak Park, Ill.
School Science Review, S. W. Read, 31 Grosvenor Road, Chichester, Sussex, England.
Science, A.A.A.S , 1515 Massachusetts Ave. N. W., Washington 5.
Science Counselor, Duquesne Univ., 901 Vickroy St., Pittsburgh 19, Pa.
Science Education, Clarence Pruitt, ed., National Association for Research in Science Teaching, U. of Tampa, Florida.
Science Education, 374 Broadway, Albany, N. Y.
Science News Letter, Science Service, 1719 N St. N. W., Washington 6.
Scientific American, Scientific American, Inc., 415 Madison Ave , New York 17.
Sky and Telescope, Harvard Observatory, Cambridge 38, Mass.
The Science Teacher, National Science Teachers Association, 1201 16 St. N. W., Washington 6.
Turtox News, General Bio. Supply House, 761 E. 69 Pl., Chicago 37.
World Science Review, 11 Eaton Place, London, S. W. 1.
Weatherwise, American Meteorological Society, 3 Joy St., Boston 8, Mass.
Welch Physics and Chemistry Digest, and *Welch General Science and Biology Digest*, W. M. Welch Scientific Co., 1515 N. Sedgwick St., Chicago 10, Ill.

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Science Education in American Schools, National Society for the Study of Education, Forty-sixth Yearbook, Part I, University of Chicago Press, 1947.
Science in General Education, Progressive Education Association, Appleton-Century-Crofts, 1938.
Science in Secondary Schools Today, National Association of Secondary School Principals Bulletin, Vol. 37, No. 191, January 1953.
Yearbooks of the United States Department of Agriculture, Washington, D. C. Obtain through your congressman.

F. PAPERBACKS AND INEXPENSIVE BOOKS OF INTEREST TO THE SCIENCE TEACHER

Astronomy and geology

Astronomy, Miller, Bellman Publishing Co., P. O. Box 172, Cambridge 38, Mass.
Biography of the Earth, Gamow, New American Library.

Birth and Death of the Sun, Gamow, New American Library.
Birth and Development of Geological Sciences, Adams, Dover Publications.
Creation of the Universe, Gamow, Compass Books, Viking.
Dictionary of Geology, Himus, Penguin.
Discover the Stars, Johnson and Adler, Sentinel Books, 112 E. 19 St., New York 3.
Discoveries and Opinions of Galileo, Drake, Anchor Books, Doubleday.
Exploration of Space, Clarke, Pocket Books.
Frontiers of Astronomy, Hoyle, New American Library
Geology in the Service of Man, Fearnsides & Bulman, Penguin.
History of Astronomy, Thales to Kepler, Dreyer, Dover Publications.
How to Know the Minerals and Rocks, Pearl, New American Library.
Key to the Heavens, Mattersdorf, Premier Books, Fawcett.
Life on Other Worlds, Jones, New American Library.
Nature of the Universe, Lucretius, Penguin.
New Astronomy, Scientific American, Simon and Schuster.
One Two Three—Infinity, Gamow, New American Library.
Origin of the Earth, Smart, Penguin.
Principles of Geology, Field, Barnes & Noble.
Rocks and Minerals, Pearl, Barnes & Noble.
Universe, Scientific American, Simon and Schuster.
Universe & Dr. Einstein, Barnett, New American Library.
World of Copernicus, Armitage, New American Library.

Biology

Atomic Radiation and Life, Alexander, Penguin.
Bees, von Frisch, Cornell University Press, 124 Roberts Pl., Ithaca, N. Y.
Dictionary of Biology, Johnson & Abercrombie, Penguin.
Elements of Physical Biology, Lotka, Dover Publications.
Fascinating Insect World of Fabre. Teale, Premier Books, Fawcett.
General Biology, Alexander, Barnes & Noble.
General Botany, Fuller, Barnes & Noble.
General Zoology, Alexander, Barnes & Noble.
Genetics, Kalmus, Penguin.
Human Use of Human Beings, Wiener, Anchor Books, Doubleday.
Living Tide, Berrill, Premier Books, Fawcett.
Origin of Species, Darwin, Frederick Ungar Publishing Co., 105 E. 24 St., New York 10, N. Y.
Physics and Chemistry of Life, Scientific American, Simon and Schuster.
Plant Life, Scientific American, Simon and Schuster.
Sea Around Us, Carson, New American Library.

Chemistry

Alchemy, Holmyard, Penguin.
Chemical Industry, Williams, Penguin.
Chemistry, Hutton, Penguin.
Crucibles, Jaffe, Premier Books, Fawcett.
Metals in the Service of Man, Street, Penguin.
New Chemistry, Scientific American, Simon and Schuster.
Organic Chemistry, Degering et al., Barnes & Noble.
Physical Chemistry, Kittsley, Barnes & Noble.

History and philosophy

The Arabs, Hitti, Gateway Books, Henry Regnery Co., 64 E. Jackson Blvd., Chicago 4, Ill.
Concerning the Nature of Things, Bragg, Dover Publications.
Copernicus to Einstein, Reichenbach, Wisdom Library, Philosophical Library, Inc., 15 E. 40 St., New York 16, N. Y.
Evolution of Scientific Thought, D'Abro, Dover Publications.
Experiment and Theory in Physics, Born, Dover Publications.
Foundations of Experimental Science, Campbell, Dover Publications.
Foundations of Physics, Lindsay & Margenau, Dover Publications.
From Magic to Science, Singer, Dover Publications.
Great Essays in Science, Gardner, Pocket Books.
Greek Science, Farrington, Penguin.
Lives in Science, Scientific American, Simon and Schuster.
Magic, Science, and Religion, Malinowski, Anchor Books, Doubleday.
Man on His Nature, Sherrington, Anchor Books, Doubleday.
Nature of Physical Theory, Bridgman, Dover Publications.
New Worlds of Modern Science, Engel, Dell Publishing Co., 750 Third Ave., New York 16, N. Y.
Science and Hypothesis, Poincaré, Dover Publications.
What Happened in History, Childe, Penguin.
What Is Life? Schrodinger, Anchor Books, Doubleday.
What Is Science? Campbell, Dover Publications.

Mathematics

Analytic Geometry, Oakley, Barnes & Noble.
Asymptotic Expansions, Erdelyi, Dover Publications.
Calculus, Petersen & Graesser, Littlefield, Adams & Co., 128 Oliver St., Paterson, N. J.
College Algebra, Feinstein & Murphy, Littlefield, Adams & Co., 128 Oliver St., Paterson, N. J.
College Algebra, Moore, Barnes & Noble.
Descriptive Geometry, Slaby, Barnes & Noble.
Dictionary of Mathematics, McDowell, Wisdom Library, Philosophical Library, Inc., 15 E. 40 St., New York 16, N. Y.
The Elements (3 vols.), Euclid, Dover Publications.
Famous Problems of Elementary Geometry, Klein, Dover Publications.
The Geometry, Descartes, Dover Publications.
Geometry of Four Dimensions, Manning, Dover Publications.
Introduction to Theory of Groups, Carmichael, Dover Publications.
Introduction to Theory of Numbers, Dickson, Dover Publications.
Mathematics, Magic, and Mystery, Gardner, Dover Publications.
Non-Euclidean Geometry, Bonola, Dover Publications.
Number, the Language of Science, Dantzig, Anchor Books, Doubleday.
Prelude to Mathematics, Sawyer, Penguin.
Principles of Relativity, Einstein et al., Dover Publications.
Statistical Methods, Arkin & Colton, Barnes & Noble.

Physics

Atomic Power, Scientific American, Simon and Schuster.
Automatic Control, Scientific American, Simon and Schuster.
Dialogues Concerning Two New Sciences, Galileo, Dover Publications.
Matter and Light, de Broglie, Dover Publications.
Optics, Newton, Dover Publications.
Our Friend the Atom, Haber, Dell.
Physics: First Year College, Bennett, Barnes & Noble.
Physics Made Simple, Freeman, Made Simple Books, Doubleday.
Revolution in Physics, de Broglie, Noonday Press, 80 E 11 St., New York 3, N. Y.
Rise of the New Physics (2 vols.), D'Abro, Dover Publications.
Science of Flight, Sutton, Penguin.

G. LIST OF PUBLISHERS

Because of the frequent appearance of new textbooks in science and the revision of existing texts, no attempt has been made to list texts. The following list of publishers includes textbook publishers (*), review and workbook publishers (**), as well as most of the publishers mentioned in the reference section.

Abelard-Schuman, Inc., 404 4th Ave., New York 16.
*Allyn and Bacon, 150 Tremont St., Boston 11.
*American Book Company, 55 5th Ave., New York 3.
**Amsco School Publications, 45 E. 17th St., New York.
Appleton-Century-Crofts, Inc., 35 W. 32nd St., New York 1.
Barnes & Noble, 105 5th Ave., New York 3.
**Barron's Educational Service, Inc., 343 Great Neck Rd., Great Neck, N. Y.
**Cambridge Book Company, 6 Varick Street, New York.
Chemical Rubber Company, 1900 W. 112th St., Cleveland, Ohio.
Childrens Press, Inc., Jackson Blvd. and Racine Ave., Chicago 7.
**College Entrance Book Co., 104 5th Ave., New York.
The Thomas Y. Crowell Co., 432 4th Ave., New York 16.
Crown Publishers, Inc., 419 4th Ave., New York.
John Day Co., Inc., 62 W. 45th St., New York 36.
Dell Publishing Co., Inc., 750 3rd Ave., New York 16.
Didier Publications, 660 Madison Ave., New York.
Dodd, Mead & Co., 432 4th Ave., New York 16.
Doubleday & Co., Inc., Garden City, N. Y.
Dover Publications, Inc., 920 Broadway, New York 10.
The Dryden Press, Inc., 31 W. 54th St., New York 19.
E. P. Dutton and Co., Inc., 286-302 4th Ave., New York 10.
The Exposition Press, 386 4th Ave., New York.
Fawcett Publications, Inc., Fawcett Bldg., Greenwich, Conn.
Garden City Books, 575 Madison Ave., New York 22.
*Ginn and Company, Statler Bldg., Boston.
Grosset & Dunlap, 1107 Broadway, New York 10.
*Harcourt, Brace and Co., 383 Madison Avenue, New York 17.
Harper & Brothers, 49 E. 33rd St., New York 16.
D. C. Heath and Co., 285 Columbus Ave., Boston.

Henry Holt & Co., Inc., 383 Madison Ave., New York 17.
Houghton Mifflin Co., 2 Park St., Boston.
International Publishing Co., Inc., 381 4th Ave., New York.
International Textbook Co., 1001 Wyoming Ave., Scranton, Pa.
*Iroquois Publishing Co., Inc., Iroquois Blvd., Syracuse, N. Y.
Alfred A. Knopf, Inc., 501 Madison Ave., New York 22.
J. B. Lippincott Co., E. Washington Sq., Philadelphia, Pa.
Lothrop, Lee & Shepard Co., Inc., 419 4th Ave., New York 16.
McGraw-Hill Book Co., 330 W. 42nd Street, New York 36.
David McKay Co., Inc., 55 5th Ave., New York 3.
The Macmillan Co., 60 5th Ave., New York 11.
William Morrow & Co., Inc., 425 4th Ave., New York 16.
National Audubon Society, 1000 5th Ave., New York.
New American Library, 501 Madison Ave., New York 22.
**Oxford Book Co., Inc., 222 4th Ave., New York 3.
Oxford University Press, Inc., 114 5th Ave., New York 11.
Pantheon Books, Inc., 333 6th Ave., New York 14.
Penguin Books, Inc., 3300 Clipper Mill Rd., Baltimore 11, Md.
Pocket Books, Inc., 630 5th Ave., New York 20.
Prentice-Hall, Inc., Englewood Cliffs, N. J.
G. P. Putnam's Sons, 210 Madison Ave., New York.
Random House, Inc., 457 Madison Ave., New York 22.
Rinehart & Co., Inc., 232 Madison Ave., New York 16.
Row, Peterson and Co., 1911 Ridge Ave., Evanston, Ill.
Charles Scribner's Sons, 597 5th Ave., New York 17.
*Scott, Foresman & Co., 433 E. Erie St., Chicago 11.
*Silver Burdett Co., Park Ave. and Columbia Rd., Morristown, N. J.
*The L. W. Singer Co., Inc., 249 W. Erie Blvd., Syracuse, N. Y.
Simon and Schuster, Inc., 630 5th Ave., New York 20.
Vanguard Press, 424 Madison Ave., New York 17.
*D. Van Nostrand Co , Inc., 120 Alexander St., Princeton, N. J.
The Viking Press, Inc., 625 Madison Ave., New York 22
Franklin Watts, Inc., 699 Madison Ave., New York 21.
Wilcox & Follett Co., 1000 W. Washington Blvd., Chicago 7.
John Wiley & Sons, 440 4th Ave., New York 16.
*The John C. Winston Co., 1010 Arch St., Philadelphia 7.

H. LISTINGS OF FILMS AND FILMSTRIPS

3434 U. S. Government Films, Office of Education, U. S. Govt. Printing Office, Washington 25, D. C., $.70.
Blue Book of 16-mm. Films, Educational Screen, 64 E. Lake St., Chicago 1, $1.50.
Directory of 2600 Film Libraries (16 mm.), Office of Education, U. S. Govt. Printing Office, Washington 25, D. C., $.35.
Educational Film Guide, H. W. Wilson Co., 950 University Ave., New York 52, $3.00.
Educator's Guide to Free Films, Educator's Progress Service, Randolph, Wisc., $5.00.
Educator's Guide to Free Slidefilms, Educator's Progress Service, Randolph, Wisc., $4.00.

Evaluation of Current Films (monthly), Educational Film Library Association
Film Library Catalogue, Dept. of Commerce, Albany 1, N. Y.
Filmstrip Guide, H. W. Wilson Co., 950 University Ave., New York 52, $3.00.
Films for Classroom Use, Teaching Film Custodians, Inc., 25 W. 43 St., New York 36.
Filmstrips: A Descriptive Index and User's Guide, Falconer, McGraw-Hill Book Co., New York, $5.00.
Films, Recordings, and Slides, N. Y. State College of Agriculture, Cornell U., Ithaca, N. Y.
General Motors Motion Picture Catalog, General Motors Corp., Detroit 2, or [illegible] Montgomery St., San Francisco 4.
Lifelong Learning, Dept. Visual Institute, U. of California, Berkeley 4.
Mental Health Motion Pictures, U. S. Dept. Health, Education, and Welfare Washington 25, D. C., $.35.
Modern Index and Guide to Free Educational Films from Industry, Modern Talking Picture Service, Inc., 45 Rockefeller Plaza, New York 20.
Motion Pictures and Slide Films, General Electric Film Library, P. O. Box 5970A 840 South Canal St., Chicago; or Peachtree Rd., Atlanta; or 4966 Woodland Ave., Cleveland; or 1801 N. Lamar St., Dallas; or 710 2d Ave., Seattle.
Reference Catalog of Medical Films and Filmstrips, Veterans Administration, Washington, D. C.
Shell Motion Picture Catalogue, Film Library 50 W. 50 St., New York 20; or 100 Bush St., San Francisco 6.
U. S. Govt. Films for Schools and Industry, United World Films, Inc., 1445 Park Ave., New York 29 (depository agency of U. S. Office Education films, and many government films).

Periodicals reviewing films and filmstrips

Audio-Visual Guide
Educational Screen
Film World and AV World
See and Hear

I. SOURCES OF SCIENCE EQUIPMENT AND SUPPLIES

Sources of equipment are classified by Richardson as trade and local.[2] Local sources are those that are found in the community. These are important to the science teacher since they are quick sources of materials. Trade resources are companies that specialize in apparatus of various types. Some companies specialize in chemicals, while others may specialize in physics apparatus; some specialize in both.

auto-salvage shop
camera shop
drug store
electric shop
five-and-ten cent store
fuel yard
grocery store
hardware store
lumberyard
plumbing shop
radio-repair shop
school store
tin shop and machine shop [3]

[2] Richardson, J., *School Facilities for Science Instruction.*
[3] *Ibid.*

The equipment and materials obtainable from each of these sources vary greatly, but the list following each source is suggestive of the resources which the science teacher may expect to find.[4]

Auto-salvage shop

- Batteries
- Carburetors
- Differential
- Engines
- Fuses
- Generators
- Headlight bulbs
- Headlight reflectors
- Induction coils
- Instruments
  - Ammeter
  - Fuel gauge
  - Speedometer
  - Thermometer
- Magnetos
- Metal tubing
- Safety glass
- Small motors
- Spark plugs

Camera shop

- Blueprint paper
- Cameras
- Contact and enlarging paper
- Developers, fixers
- Enlargers
- Exposure meters
- Film
- Timers
- Trays and tanks

Drug store

- Chemicals
- First-aid materials
- Photographic supplies
- Proprietary products

Five-and-ten cent store

- Aluminum sheet
- Brass wire
- Cellophane
- Electrical equipment
- Fish line
- Flashlights
- Bulletin board
- Friction tape
- Glue
- Iron wire
- Lacquer and varnish
- Mirrors
- Paint
- Ping-pong balls
- Rubber balloons
- Sandpaper
- Screws, nuts, bolts
- Suction cups
- Springs
- Tape measures
- Thermometers
- Thread
- Tools
- Toys
  - Electromagnets
  - Gyroscopes
  - Magnets
  - Marbles
  - Xylophones

Grocery store

- Baking powder
- Bleaching solution
- Bluing
- Carbonated water
- Corn syrup
- Epsom salts
- Matches
- Mineral oil
- Paraffin
- Saccharin
- Sealing wax
- Sodium bicarbonate
- Starch
- String
- Sugar
- Table salt
- Turpentine

Hardware store

- Abrasives
- Aluminum sheet
- Bolts

[4] *Ibid.*

- Brass rods
- Brass sheets
- Brass wire
- Celluloid sheet
- Clothespins
- Copper wire
- Cord
- Electrical supplies
  - Doorbells and buzzers
  - Dry cells
  - Fluorescent lighting
  - Fuses
  - Insulation
  - Light bulbs
  - Motors
  - Plugs
  - Resistance units
  - Sockets
  - Solder
  - Switches
  - Transformers
  - Wire
- Fishline
- Glass sheet
- Iron sheet, bar, rod
- Lacquer
- Lead
- Paint
- Nails
- Pulleys
- Screws
- Screw eyes
- Screw hooks
- Springs
- Tape measures
- Thermometers
- Thermostats
- Tools
  - Emery wheels
  - Hammers
  - Hand drills
  - Planes
  - Pliers
  - Saws
  - Screw drivers
  - Soldering irons
- Turnbuckles
- Twine
- Varnish
- V-belts
- White lead

Lumberyard

- Glass sheet
- Hardware
- Insulation
- Lime
- Lumber
- Paint
- Plaster
- Varnish

Radio-repair shop

- Choke coils
- Condensers
- Cores from discarded transformers
- Electrical instruments
- Radio tubes
- Rheostats
- Solder
- Transformers
- Wire

School store

- Erasers
- Friction tape
- Fuses
- Ink
- Light bulbs
- Oil
- Paper
- Paper towels
- Pencils
- Soap
- Wire

Tin shop and machine shop

- Ball bearings
- Rods of various materials
- Screws, bolts, rivets, etc.
- Sheet metal

Miscellaneous

- Billiard balls from game parlors
- Coal from the local coalyards
- Dry ice from the school cafeteria or delicatessen
- Fabrics from the drygoods stores
- Gasoline and oil from the service stations
- Ice from the school cafeteria and the ice plant

J. SOURCES OF LABORATORY FURNITURE

Browne-Morse Co.
110 Broadway
Muskegon, Mich.

Equipment & Furniture Co., Inc.
116 E. 32nd Street
New York, N. Y.

Hamilton Manufacturing Company
1935 Evans Street
Two Rivers, Wisc.

Kewaunee Manufacturing Company
5019 S. Center Street
Adrian, Mich.

Maurice A. Knight
Akron, Ohio

Laboratory Furniture Co., Inc.
3720 Northern Blvd.
Long Island City, N. Y.

Metalab Equipment Corporation
210 Duffy Avenue
Hicksville, N. Y.

Leonard Peterson & Co., Inc.
Fullerton and Racine Avenues
Chicago, Ill.

E. H. Sheldon and Company
149 Thomas Street
Muskegon, Mich.

W. M. Welch Manufacturing Co.
1515 Sedgwich St.
Chicago, Ill.

K. ADDRESSES OF SUPPLY HOUSES

Ainsworth & Sons, Inc., 2151 Lawrence St., Denver 5.
Allied Chemical & Dye Corp., 40 Rector St., New York 6.
Aloe Scientific, Division of A. S. Aloe Co., 5655 Kingsbury St., St. Louis 12.
American Hospital Supply Corp., 40-05 168 St., Flushing, N. Y., or 2020 Ridge Ave., Evanston, Ill.
American Optical Co., Buffalo 15, N. Y.
American Type Culture Collection (bacteria), 2020 M St., N.W., Washington 6, D. C.
Bausch and Lomb Optical Co., 635 St. Paul St., Rochester, N. Y.
Biddle & Company, 1316 Arch St., Philadelphia 7.
Biological Research Products Co., 243 W. Root St., Chicago.
California Biological Service, 1612 W. Glenoaks Blvd., Glendale.
California Botanical Materials Co., 861 E. Columbia Ave., Pomona.
Cambosco Scientific Co., 37 Antwerp St., Brighton 35, Mass.
Carolina Biological Supply Co., Elon College, N. C.
Central Scientific Co., 1700 N. Irving Park Rd., Chicago 13.
Certified Blood Donor Service, 146-16 Hillside Ave., Jamaica 35, N. Y.
Chicago Apparatus Co., 1735 N. Ashland Ave., Chicago 22.
Clay-Adams Co., 141 E. 25 St., New York 10.
Corning Glass Works, Corning, N. Y.
Denoyer-Geppert Co., 5235 N. Ravenswood Ave., Chicago 40.
Difco Laboratories, Inc., Detroit 1.
Dow Chemical Co., Midland, Mich.
Eastman Kodak Co., 343 State St., Rochester 4, N. Y.
Eimer and Amend, Greenwich and Morton Sts., New York 14.
Erb & Gray Co., 854 S. Figueroa St., Los Angeles 14.
Fisher Scientific Supply Co., 139 Fisher Bldg., Pittsburgh 19.
General Biochemicals, Inc., 677 Laboratory Park, Chagrin Falls, Ohio.

General Biological Supply House, Inc. (Turtox), 8200 S. Hoyne Ave., Chicago 20.
Gradwohl Laboratories, 3514 Lucas Ave., St. Louis 3.
Graf-Apsco Co., 5868 N. Broadway, Chicago 40.
Harshaw Scientific Division, Harshaw Chemical Co., 1945 E. 97 St, Cleveland 6.
Kelly-Koett Manufacturing Co., 24 E. 6th St., Covington, Ky.
Kimble Glass, P.O. Box 1035, Toledo 1, Ohio.
Knickerbocker Blood Donor Service, 300 W. 43 St., New York.
Charles Lane Corp. (cabinets), 105 Chambers St., New York 7.
Lederle Laboratories, Div. American Cyanamid Co., Midtown Rd., Pearl River, N. Y.
Leitz, Inc., 468 4th Ave., New York 16.
Los Angeles Biological Laboratories, 2977 W. 14 St., Los Angeles 6.
Marine Biological Laboratory, Woods Hole, Mass.
Merck & Co., Rahway, N. J.
Monsanto Chemical Co., 1700 S. 2d St., St. Louis 4.
Nalge Co., Inc. (plastic ware), Rochester 2, New York
New York Scientific Supply Co., 28 W. 30 St., New York
Nutritional Biochemicals Corp., 21010 Miles Ave., Cleveland 2
Nystrom & Co., 3333 N. Elston Ave., Chicago 18.
Oregon Biological Supply Co., 1806 S.E. Holgate Blvd., Portland.
Pacific Laboratory Apparatus Co., 3555 Whittier Blvd., Los Angeles 23.
Polaroid Corp., Cambridge 39, Mass.
Product Design Co. (conservation kits), 2796 Middlefield Rd., Redwood City, Calif.
Charles Pfizer & Co., 11 Bartlett St., Brooklyn, N. Y.
Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.
Sheldon Equipment Co., 149 Thomas St., Muskegon, Mich.
Sprague-Dawley, Inc. (laboratory rats), P.O. Box 2071, Madison 5, Wisc.
Standard Scientific Corp., 34 W. 4th St., New York.
Testa Manufacturing Co., 418 S. Pecan St., Los Angeles 33.
United Scientific Co., 204 Milk St., Boston 9.
Ward's Natural Science Establishment, 3000 Ridge Rd. E., Rochester 9, N. Y.
Welch Manufacturing Co., 1515 N. Sedgwick St., Chicago 10.
Western Laboratories, 826 Q St., Lincoln, Neb.
Windsor Biology Gardens, Moore's Creek Rd., Bloomington, Ind.

L. LISTINGS OF FREE AND INEXPENSIVE SCIENCE MATERIALS

Sources of Free and Inexpensive Educational Materials, Field Enterprises, Inc., Education Division, Merchandise Mart Plaza, Chicago 54, 1955, $5.00.
Free and Inexpensive Learning Materials, George Peabody College for Teachers Division of Surveys and Field Services, Nashville 5, Tenn., 1956, $1.00.
Sources of Teaching Materials, C. Williams, Bur. Educational Research, Ohio State U., 1955.
Sources of Free and Inexpensive Pictures for the Classroom, B. Miller, Box 369, Riverside, Calif., 1956, $.50.
Free and Inexpensive Teaching Aids for High Schools, C. Holland, Nat. Assoc. Secondary School Principals, N.E.A., 1201 16 Street N. W., Washington 6, D. C., 1949, $1.00.

Sources of Free and Inexpensive Materials in Health Education, Teachers College, Temple U., Curriculum Laboratory, 1954, $.25.

"Free and Inexpensive Teaching Materials For Science Education," M. Beuschlein and J. Sanders, *Chicago Schools Journal,* vol. 34, Nos. 5, 6, 1953 (available as reprint).

Conservation Teaching Aids, Michigan Dept. Conservation, Education Division, 1951.

Catalog of Man and Nature Publications, Amer. Museum Natural History, New York, 24.

Health Materials and Resources for Oregon Teachers, State Dept. Education, Salem, Ore., 1955.

1001 Valuable Things Free, 2d ed., M. Weisinger, Bantam Books, New York, 1957.

A Wonderful World for Children (free and inexpensive materials), P. Cardozo, Bantam Books, New York, 1956.

General Motors Aids to Educators, General Motors Corp., 1956.

Catalog of Free Educational Material on the Banana and Related Subjects, United Fruit Company, Educational Service Dept., Pier 3, North River, New York, 6.

Choosing Free Materials for Use in the Schools, Amer. Assoc. of School Administrators, N.E.A., 1201 16th Street N. W., Washington 6, D. C., 1955, $.50.

Using Free Materials in the Classroom, Association Supervision and Curriculum Development, N.E.A., 1201 16 St. N. W., Washington 6, D. C., 1953, $.75.

Sponsor Handbook: Thousands of Science Projects, Science Service, 1719 St. N. W., Washington 6, D. C., 1957, $.25.

Teaching Aids, Westinghouse Electrical Corp., School Service, 306 4th Ave., Pittsburgh 30.

Hobby Publications, Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C.

encyclopedias, and use imagination to provide the incidents. They can also find a wealth of detail in biographical accounts, much of which is dramatic enough to be set directly in play form.

Occasionally science plays are published in education journals; titles may be found in the *Education Index*. *School Science and Mathematics* can furnish reprints of some of these.

The preparation of science programs for all-school assemblies provides unusual learning opportunities for pupils. The planning process, as ideas are proposed, discussed, and judged, is richly rewarding. Ingenuity is challenged during the preparation of properties, scenery and special effects. Production and presentation provide experiences not afforded by regular classroom work. Some teachers feel justified in making the preparation of an assembly program the equivalent of a regular unit of study.

Programs made up of a number of short features—skits, talks, demonstrations, novelty acts, tableaux and the like—are relatively simple to produce. Responsibilities can be apportioned among several groups of pupils to permit full participation. Two or more teachers can divide up the direction more easily.

The five biology sections of the Alexander Hamilton High School presented ten tableaux, or living pictures, called "Great Moments in Medicine." Among the scenes pictured were the first vaccination, the first use of antiseptic surgery, and the first use of an anesthetic. Narrators explained the importance of each scene.

A run-down sheet of the type shown below is helpful in planning and producing programs made up of many short features.

Run-down sheet for assembly program on airplane flight

Scene I

1. Recording of flight sounds. Lights up. Curtain up
2. Announcement of purpose of program
3. Demonstrations of Bernoulli's principle—Shadow projection
4. Demonstration of lifting effect on wing section
5. Projection of slides showing pressure distribution on wings
6. Flight of rubber-band powered model
7. Curtain

Scene II

1. Flight sounds. Lights up. Curtain up
2. Demonstrations of rotational axes of airplane
3. Demonstration of effects of wind on control surfaces of models
4. Demonstration of large skeleton model showing how pilot moves control surfaces
5. Demonstration in center of auditorium of flight of controllable model
6. Curtain

Scene III

1. Flight sounds. Curtain up. Back drops part
2. Demonstration of action of "Link Trainer" model built by boys
3. Recording "The Air Force Song." Final curtain

The run-down sheet states the unifying theme and shows the sequence. It guides stage managers, electricians, property men, and the director or directors. It becomes the basis for the program given to the audience.

All programs should be planned with the nature of the adolescent audience in mind. Action should be fast paced; there should be no long lapses. Suspense is essential, with a gradual building up towards the final climax. Comic relief can be provided by inserting comedy scenes or by using a clown who stumbles around parodying serious members of the cast and getting in everyone's way except at critical moments.

Television and radio programs. Much that has been said about assembly programs applies to television programs. Many of the same benefits to the participants can be expected, although television program directors do not usually permit pupils to make as many decisions as would be allowed in the production of programs for school audiences.

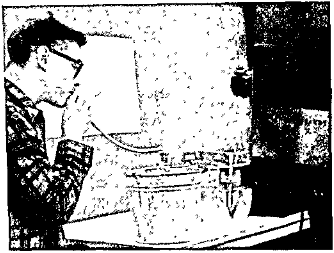
As with assembly programs, action should be rapid; at all times there should be something going on for the cameras to pick up. Emphasis should be put on spectacular demonstrations, the display of active animals, and the like; dialogue should be minimized. Humor is always an asset.

Television has certain advantages in the production of science programs. Through the medium of the long focus lens the audience can be brought close to demonstrations, a fact that permits the use of smaller materials than can be used in auditoriums where visibility is always a problem. A television program director can also send a camera man away from the studio to film special scenes that can be woven into the program; these are silent but can be given meaning by a narrator.

As with assembly programs, three or four short skits are easier to produce than one long feature, and they permit more pupils to participate both as actors and property men. A run-down sheet is helpful in holding the program together and may be required by the television program director.

Radio programs are relatively more difficult to produce effectively than television programs. Through words alone the audience must be given a picture of what is going on. This limits science programs

to materials familiar to the audience. Reference to the sour taste of a lemon, the "lightness" of cork, and the feel of wool are immediately intelligible. But no amount of description can give a meaningful picture of a Bunsen burner or a Florence flask to the adult with no training in science.



Television, radio, and assembly programs based on science subjects can be of interest to any audience and at the same time give the participants excellent practice in writing and producing the program. Television has the added advantage of making experiments with small scale materials readily visible.

The problem of identifying participants is equally difficult. Since voice quality is the only recognizable characteristic a few participants with unlike voices should be used; two boys and two girls make a good balance, with perhaps an adult voice added if necessary for the action. The audience can be helped in identification of voices by the frequent use of names as the participants address each other.

Though most of the action must be implied by the words of the participants, a narrator may be used to describe what is going on. His voice should be different and he should speak in a more deliberate fashion so that he is easily identified when he breaks into the program.

Pupils love sound effects, but these are not easy to build into the program. Many things do not sound on the air as they do in actuality. Commonly they must be identified for the listener, and timing is always important. If the program can be taped in advance, pupils will have opportunities to experiment and discard sound effects that are not suitable.

Participants in radio programs work from scripts that permit close control of the situation. However, there is danger that as pupils read these scripts naturalness will be lost. To avoid this it is well to give the participants only short sentences, phrases and exclamations to read. Rarely should one person have a line of more than one short sentence. Sentences containing dependent clauses should be broken into two separate sentences and assigned to different individuals. Even poor readers, who benefit greatly from such experiences, can participate with this type of script. A portion of a science radio program script illustrating some of the points made above is shown below. Note the short direct sentences, each expressing a single idea, and note the distribution of the lines among the participants. These devices make reading easier, give an effect of spontaneity, and help maintain listener attention through constant change of voice and manner of delivery.

Teacher:	You pick out something this time, Dixie. Shut your eyes and reach in the box.
Dixie:	(Short pause): Here!
Bill:	It looks like a can.
Dave:	I know what it is. It's a "Come-back."
Bill:	What's that?
Dave:	You roll it along the floor. Pretty soon it stops and rolls right back to you.
Teacher:	Show us, Dave.
Dave:	(Pause): All right. Now watch. See it rolls right back to me.
Bill:	I see. That's why it's called a "come-back."
Dixie:	What makes it work?
Teacher:	I think I can show you. This end pulls off.
Karen:	There's just a rubber band and something hanging on it.
Teacher:	That's a weight hanging on the rubber band, Karen.
Bill:	Let's see. When you roll it ——.
	Oh! I understand. When you roll it the rubber band twists up.
Teacher:	Here, Bill. See if you can show us.
Bill:	See, when I turn the can the weight winds up the rubber band.
Dave:	Then the rubber band unwinds and makes the toy came back to us.
Teacher:	We could say that energy is stored in the rubber band, couldn't we?
Dixie:	Why, yes. That's where it is stored.
Karen:	Where is it stored in the toy automobile?
Teacher:	Did you ever see one taken apart?
Bill:	Yes, I have. There's a spring in there.
Teacher:	So the energy is stored in the spring.
Dave:	There's a spring in the clock, too.

Some science radio programs may be of the panel type. These are useful in describing field work, visitations and special events. An in-

terviewer may ask questions of the panel or a moderator may direct the conversation. For this sort of program "skeleton" scripts may be sufficient. The following "skeleton" script was written for one of a series of radio programs reporting the field observations of a science class. The key words or phrases guide each participant but allow him to express himself in his own way.

Mr. Baker—A week ago on this program we told about our first field trip at five below zero. We didn't do any better this time, did we, Miss Miller?
Anne —Colder.
Joe —About the same on the trip—colder night before.
Jack —More animal signs seen.
Terry —Have interest in tracks. What kinds?
Jack —Name four.
Anne —Name some more.
Terry —Bird tracks seen.
Joe —Surprised at blue heron.
Mr. Baker—Sees one or more tracks yearly. Not common.

MORE AND BETTER WRITING

Secondary school pupils are notoriously reluctant to write. Few of them write for pleasure. Most do only such writing as is required. Some write only under duress.

Skill in writing is too important to be ignored by science teachers. They share with all other teachers the obligation to help pupils develop this skill. Sometimes, science teachers are best situated to provide the needed stimulus.

Encouraging pupils to write. By the time a pupil has reached the secondary school he has gained sufficient word power and writing skill to express himself on paper. He may, and probably does, write with a scrawl. He may misspell words. He may break rules of grammar or omit punctuation marks. But he can convey his thoughts to a reader.

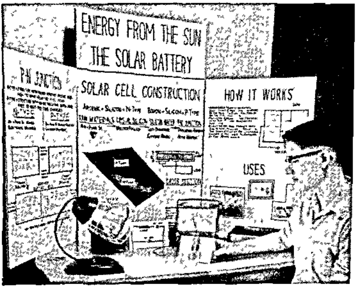
This pupil has the ability to use writing for communication, which after all is the principal function of writing. Admittedly, he is unconscious of certain refinements that make communication easier, but this represents lack of experience, not incompetence. He needs practice, not in the narrow sense of the term, but through purposeful writing experiences.

The briefer forms of communication, such as labels and captions, are apt to go unnoticed in the search for valuable writing experiences.

Actually, brief communications give excellent practice with words and terse expressions. Best of all, pupils are able to judge the effectiveness of their own writing and make improvements when needed.

More extensive writing projects for the science program may be suggested in unlimited numbers, but pupils do not always undertake them willingly. For years they have been compelled to write and rewrite papers destined only for the ash can. They no longer feel pleasure in writing to express themselves. The science teacher must use special efforts to establish a strong sense of purpose in his pupils.

Pupils usually see the advantage of supplementing an exhibit with a short paragraph or so. When they have exerted themselves in independent research—field work, original experimentation, and the like, they recognize the need for reports. They like the prestige that comes with preparing notes for publication. They can be challenged by such group projects as play writing.



The preparation of labels for an exhibit represents a valuable writing experience. This boy has had practice in concise writing, in organization of ideas, and in the mechanics of printing. Some pupils who would not otherwise engage in written communication will prepare labels diligently.

The teacher can give a great deal of help in organization. Commonly one long report can be broken into several minor projects, each of which can be undertaken separately and polished as needed. Sometimes an outline is needed. Usually suggestions for the use of visual aids are required.

The teacher must develop a constructive attitude when evaluating the written work of his pupils. He should train himself to look beyond the mere mechanics of spelling, punctuation and grammar, remembering that what is said is the important thing. He should note efforts to organize, to select descriptive words, to provide emphasis. Whenever he can, he should give praise for a picturesque phrase, a lucid sentence, and a well-constructed paragraph.

Discovery and correction of minor errors can often be left to the pupils themselves when they have a purpose for providing fault-free written materials. An elementary teacher describes a technique that could be used equally well in the secondary school:

My fifth grade had set up and labeled the exhibits for a science show to which parents were invited. The pupils agreed that the labels should not be misspelled or have other serious mistakes. So they chose three committees, one to check spelling, one to criticize sentences and word usage, and a third to judge neatness. These committees were harsher than I would have been but their decisions were accepted by their classmates. It was a valuable experience for everyone.

The use of editorial committees as just described can solve many problems for the teacher. Committees may check entries in science shows. They may check the work of bulletin board committees. Materials produced for duplication—committee reports, summaries, pupil-planned demonstrations, and the like—should be edited. And any articles submitted for publication in the school or local newspapers need careful editing. Pupils learn to be critical. They get in some interesting arguments and they learn to appeal to proper authorities—dictionaries, grammars, and secretaries' handbooks.

Minor writing experiences. The preparation of labels for exhibits gives practice with spelling, printing, and organization of words. Often the work demands reference to a dictionary for help with spelling.

Pupils quickly see the advantage of supplementing a title with a brief but informative phrase or sentence. The writing of a caption requires considerable skill but a pupil undertakes it willingly because it is short. Some labels use common words but often the labels become quite technical as pupils do advanced reading about their interests.

Labels for nature trails may be much the same as those just described, but when they call attention to items more or less removed from the labels, as when dealing with a bird nest high in a tree, they involve special problems of writing. Again, because the captions are brief, pupils attack the task readily and do surprisingly well.

Labels that are used with working models may tell the viewer how to operate the model. These labels give pupils excellent practice in

writing directions. A label attached to an exhibit of fluorescent materials inclosed in a box is shown below:

> FLUORESCENCE
>
> The things in this box will glow when they are in ultraviolet light.
>
> 1. Look in the peephole.
> 2. Press Button A to see them by regular light.
> 3. Press Button B to see them by ultraviolet light.
>
> George Warner

Complex exhibits may require a number of separate labels which together represent an elaborate piece of writing but which, because they are separated, give pupils little trouble.

Chart making provides the same type of writing experiences as are provided by label making. A number of pupils find chart making a real challenge. They accept without question the need for appropriate headings and descriptive comments.

Pupils often become discouraged when they discover errors of spelling or produce poorly drawn letters on charts that have taken much time and energy to produce. They may abandon their projects even though nearly completed. If they are advised to make all captions on separate cards which can be attached to the charts with rubber cement, they can easily replace those on which there are errors or unsightly printing.

Bulletin board displays are much more effective when pictures and diagrams are attended by descriptive captions. There should be a single unifying title for the entire exhibit, captions for each picture or diagram, and perhaps a paragraph or two of additional information.

Among the standing committees in Mrs. Bull's chemistry sections were bulletin board committees responsible for preparing two displays each term. One committee chose to show the products derived from corn. The pictures for the display were clipped from advertisements in magazines. Labels from containers of corn products were also used. The pictures were arranged about a picture of an ear of corn and connected to it with lengths of ribbon. Labels told briefly how each product is prepared and used. In some instances the chemical processes were described.

Pupils gain valuable writing experiences by serving as class or group secretaries. When lists of words and tables of figures are to be made,

it is well for the secretary to keep records on the chalkboard so that all pupils may participate in the organization of the material, in any corrections that are needed, and in the analysis of the data. Afterwards the data may be copied off by either the secretary or all the pupils. When no extensive writing is called for, pupils who are not normally inclined to write commonly volunteer to be secretaries.

During a demonstration experiment on the burning of a candle under various conditions, it became desirable to record the data in some convenient form. A girl volunteered to be the secretary. The pupils suggested a two-column arrangement and dictated the headings for the columns. They then told the secretary how to enter the data already collected, criticizing her spelling when she made some mistakes. Then as more data were collected, they told her where entries should be made.

Sometimes a teacher may choose to provide in advance a form for the secretaries to fill in. This procedure can be justified in many cases. It does, however, deny the pupils opportunities to participate in deciding the form of organization, an important part of the writing process.

Elementary school pupils sometimes keep a class notebook or a class scrapbook. Generally, one pupil is responsible for the organization of the book, although sometimes a committee is assigned the task. All pupils contribute pictures, clippings, diagrams, paintings and written accounts. Secondary teachers might find this device a useful one to use at times.

Another technique observed in a sixth grade classroom might have value in secondary school science classes.

Miss Dixon's sixth grade kept a nature diary and Anne was the recorder. As pupils reported their observations of things they had seen outdoors, Anne collected the reports, edited them and typed them for the diary. The diary contained over a hundred pages by the end of the year, with each pupil having contributed several items, mostly short paragraphs but a few running more than a half page in length.

This nature diary gave all pupils writing experience and gave Anne considerable editorial experience. The technique should have value in the secondary school if it can be adapted to the increased maturity of the pupils.

The school newspaper may feature a science column if the idea is proposed to the editors. In one school there are class reporters who collect items of interest from the pupils, usually about special projects and sometimes about unusual observations. The reporters may edit the accounts written by the other pupils or they may write the ac-

counts themselves. Teachers must constantly remind both the reporters and the other pupils if the column is to flourish.

Major writing projects. Comparatively few pupils volunteer to undertake tasks that they know will demand extensive writing. This is partly due to reluctance to begin something they believe will be unrewarding and partly due to a feeling of incompetence in writing skills. However, when pupils become engrossed in special activities, they need only moderate encouragement to write about what they have seen and done.

Among the easier reports to organize and prepare are those based on anecdotal records. Anecdotes tend to organize themselves chronologically. As soon as one anecdote is written it may be laid aside and another started. There is no necessity for transition and development. One anecdote may be revised without affecting the others.

Seventh grade Millicent watched a robin building a nest outside her bedroom window. Each day she wrote up her observations, describing the activities of the robin and the changes in the nest. Her final report needed only an introductory paragraph to be an excellent piece of writing.

Similar to anecdotal records, in that they are composed of several discrete items, are reports that describe a number of separate but related objects, situations, or events. An organization based upon position may be used.

For a biology project, Jennifer made a study of a blueberry bog on her parents' property. She explored the bog carefully, collecting specimens and taking pictures. She incorporated her observations in a report that was illustrated with photographs and dried specimens. The report was organized in three main sections, each dealing with one of the divisions of the bog—the open portion, bushy section, and the wooded section. She added an introductory section locating the bog and indicating her interest in it. She wrote a final section giving her conclusions about the future of the bog.

Directions for carrying out processes are relatively simple to write, based as they are on step-by-step procedures that provide their own organization and that need only a brief introductory statement to be effective writing.

Ollie and Harry were as nearly incompetent academically as two boys can be and still be in the ninth grade. But they were interested in automobiles. One day their science teacher asked them if they could change tires. Both could.

"Now look," their teacher told them, "you fellows go take off a tire and put it back on. As you do it, write out each step. Then come back and I'll

let you tell the rest of the class just what you did. I want all of them to know how, so that someday when they drive their own cars they will know what to do."

The next day Ollie and Harry brought in the directions. They had been so ashamed of their crude handwriting that they had borrowed a typewriter to make a more legible copy. They were very proud of their contributions to the class.

A teacher may ask certain pupils to find experiments for their classmates, summarize the procedures, and prepare duplicated copies. The pupils then take charge of the class and supervise the laboratory work for which they have written directions.

A diagram sometimes aids pupils in organizing their reports by suggesting the nature and order of the topics to be taken up. A radio circuit diagram, for instance, gives a beginning and an ending point and includes the important intermediate steps. A flow diagram, such as that shown in figure 12, page 170, is useful in writing about a manufacturing process; it suggests that the general nature of the successive processes should be described first, then each process may be described in detail. Sometimes a map helps in the organization of a report.

James became interested in the reasons why the small river near his home veered sharply from one valley wall to the other. From a map he noticed that each sharp bend occurred opposite the mouth of a tributary valley. Field work and continued map study convinced him that alluvial fans deposited by tributary streams forced the main stream to the opposite sides of the valley.

His teacher encouraged him to write up his study as a special report for earth science. First he drew up a map of a ten-mile section of the valley and plotted the alluvial fans as he had found them through his field work. For his report, after an introductory section, he described each fan in detail and the nature of the associated bend in the main stream. A final section gave his conclusions.

Science writing may go beyond reports of project work. Play writing may become a major project for a number of pupils, as in this incident described by one teacher:

Our play writing project was one of those pupil suggestions which just grows once it gets started. In a class committee meeting someone said, "Why can't we review our work by writing a play?" So they began. Someone else suggested that they write a challenge to the other science classes to compete with them and that the best play would be given over the public address system. Not everyone responded, for play writing is not the easiest type of project. In each class the finished plays were read and the two

best plays selected by student vote. This resulted in six possible choices. One of the class presidents asked the dramatics teacher to select the winning play. She selected two, one for its interesting style and the other for its content. The result was that both girls rewrote their plays, one for greater interest and the other for more content, and both playlets were used in a freshman assembly.[1]

Science fiction appeals to many boys who are avid readers of this type of literature. Some boys who never volunteer for any other type of writing will try their hands at short, pseudo-scientific stories.

The writing of poetry appeals to a different type of pupil. Science themes suitable for poems are limitless. Sometimes pupils need a little help with this means of self-expression.

Mr. Willis used a few minutes of class time to explain to his earth science pupils the nature of a couplet. Then he suggested that each pupil try to write a couplet about a fossil trilobite found on a field trip.

Some pupils can be stimulated to write essays. Controversial topics such as "The importance of vivisection" appeal. Descriptive essays such as "The earth as seen from its satellite" may be in accord with specific interests. If sufficiently challenged, pupils will do an enormous amount of work in research and writing.

Throughout the year the science teacher may drop suggestions for stories, poems and short essays that would be appropriate for the subject under study. Always he must try to provide recognition commensurate with the efforts and achievements of the pupils who accept the challenge.

Suggested activities

1. Select at random ten definitions from the glossary of a science textbook. Analyze each from the standpoint of the experience background pupils would need for correct interpretation. In instances where pupils lack the proper background, plan the necessary procedures by which the words could be introduced to the pupils.
2. Read a science book that could be used for supplementary reading. Present an oral review of the book to the methods class, using visual aids of the type that a secondary school pupil might use.
3. List various techniques that can be used to build the pupils' scientific vocabularies.
4. Select an eighth grade general science unit. Plan writing experiences suitable for a class of pupils with a wide range of academic ability.
5. Divide the methods class into several groups and have each write and produce a science skit.

[1] Harrison, Florence, "Science Projects for Girls," *School Science and Mathematics,* October, 1943.

MORE MATHEMATICS IN THE SCIENCE PROGRAM

chapter 20

Mathematics is sometimes termed the "handmaiden" of science. But mathematics is more than a servant or a tool; it has blazed trails along which scientists have gratefully followed. The works of Maxwell and Einstein are well-known examples. Science without mathematics is unthinkable.

Nonetheless within the science program there has developed a strange dichotomy. On the one hand are the so-called "descriptive" sciences—certainly a misnomer because quantity is part of any adequate description—and on the other hand are the "mathematical" sciences which plunge immediately into complex numerical problems. This all-or-none policy has not been favorable for the intellectual growth of young people. Pupils in the "descriptive" sciences are denied valuable mathematical experiences. And pupils who lack certain mathematical prerequisites are barred from such valuable courses as physics and chemistry.

Pupils need a science program that is based upon mathematical concepts from the beginning. Only thus can they develop "number sense" and learn to appreciate the properties of numbers. This program must extend through such courses as physics and chemistry with more pupils being brought into these courses to benefit from the important concepts developed in them.

WHAT MAY BE EXPECTED OF YOUNG PEOPLE

It is but natural for science teachers to hope that pupils will come to them with full mastery of basic mathematical skills, and it is but

natural for them to complain when they are disappointed. However, expectations should be realistic; prolonged complaints based upon the unattainable lead to unhealthy attitudes.

Variation in mathematical aptitude. Within any large, unselected group of young people, the distribution of mathematical aptitude follows the normal curve; about half of the pupils lie below the "norm" and a few individuals fall far below. But the teacher should recognize the significance of the norm. All the pupils falling below this point of the curve are still intelligent beings capable of understanding quantitative aspects of science.

It is not certain whether mathematics aptitude is part of general intelligence or whether there are specific aptitudes in different aspects of mathematics. Nevertheless, pupils behave as though they have different kinds of natural abilities. One pupil may carry out routine computations swiftly and accurately but show little insight when making applications. Another pupil may show true brilliance in problem-solving situations but be unreliable in computational work.

Certainly the personality factor enters the picture, whether this be inborn or acquired. One pupil may be methodical but uninspired; his reports are beautifully organized, his computations are accurate, everything is beautifully labeled, but he needs constant help with basic understandings. Another pupil may show brilliance in his approach to problems but seem incapable of turning in acceptable papers. A science teacher will be more just in his appraisal of pupils if he assumes that such differences are due in large part to inherent characteristics rather than to laziness, poor preparation, and general incompetency.

Variation in background. Pupils who come from different school systems may vary in the training they have received. Some of the variation may be due to inevitable differences in the quality of the teaching; there are poor teachers of mathematics as well as good ones. But much of the variation may be due to differences in philosophies. Some teachers emphasize mastery of basic skills to the exclusion of all else. Others try to develop basic understandings and use time that might otherwise be devoted to drill. It is easy to condemn this latter group of teachers when faced with pupils who lack certain skills but the condemnation is rarely justified. Pupils trained in either way have limitations and compensating strengths.

Problems of transfer. Every mathematics teacher recognizes that pupils have difficulty making transfers of learning from one situation to another. A pupil may be skillful solving money problems but helpless when faced with a comparable problem involving velocities. He

must be given almost as much help with the second problem as with the first. The ability to make transfers may be one factor of general intelligence. Many pupils can make transfers to closely analogous situations but their number decreases as the similarities between the two situations decreases.

The problems of transfer are important to science teachers. Problems pupils encounter in their mathematics classes bear little resemblance to those met in science classes. Science teachers must expect to give help with transfer, often approaching problems as though pupils have had no experience with them previously. The gifted pupils will see the relationships quickly, solve the problems, and turn to more advanced work Other pupils will follow in turn as they receive adequate help. Only a few pupils will need extended help.

Differences in readiness. Most authorities agree that readiness is a factor to be considered in teaching mathematics. Some topics are better for high grade levels than low. Some pupils can master material in a short time when they are in their teens but require years to master the same material as children.

Readiness may come with maturation of the mind, which varies with individuals, or it may come with increasing experiences. Perhaps it depends upon both. The science teacher can control to some extent the experience factor. A farm boy may grasp the mathematical relationships of a pulley system quickly, while a girl who has always lived in a city apartment house may find them incomprehensible. The science teacher may plan to give her the needed experience background and thus make her more nearly ready for the quantitative aspects of the problem.

Incomplete mastery of basic processes. Any expectation that secondary pupils will have completely mastered mathematics shows a serious lack of understanding of the learning process. Mastery is not easily attained. Mere introduction to a skill is not sufficient; pupils must have some practice. After sufficient practice they may attain what can be called temporary mastery of a specific skill. However as soon as practice ceases, forgetting begins, and the longer the interval without practice the less is remembered. Reteaching and more practice is then required. Though learning is more rapid with each successive reteaching and forgetting is less rapid and less complete, permanent mastery can never be assured.

A look at a mathematics program will show why the science teacher cannot expect mastery of basic processes. A chart giving a typical program for grades one through eight is shown on pages 504-505. Pupils

in the seventh grade will have a fair mastery of the addition combinations; they have had between four and five years practice with these. But they will have been little more than introduced to percentages; they will have had almost no time for practice, relearning and additional follow-up practice.

Once these pupils pass the ninth grade, they will begin to regress in many mathematical skills unless there is some provision for reteaching fractions, decimals, percentages, and the like in higher grades. Senior high school science teachers, therefore, must expect many inadequacies.

Acquaintance with the mathematics program of his school system will help the science teacher develop realistic expectations. An eighth grade teacher, for instance, will not expect his pupils to use algebraic equations. A physics teacher will not expect pupils without intermediate algebra to handle logarithms.

An understanding of the mathematics program will make a science teacher recognize the need for reteaching. The seventh grade teacher, for instance, will plan to reteach percentages when he intends to use them. The biology teacher may recognize the need for helping his pupils with bar graphs when he asks that these be used.

MAKING THE DESCRIPTIVE SCIENCES QUANTITATIVE

Opportunities for developing the quantitative aspects of science are practically limitless. However, whatever mathematics is used should be functional and necessary to solve the problems that arise out of the pupils' experiences with science. The use of practice exercises designed solely for drill, as is so often done in physics and chemistry, will defeat the purpose of including mathematics in the descriptive sciences.

The mathematics employed should be appropriate for the achievement level of the pupils. When pupils are familiar with numbers and processes they have a feeling of competence which encourages them to use mathematics more freely.

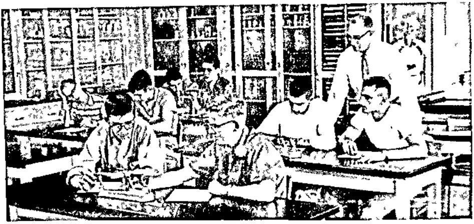
Too much cannot be said about the importance of using simple, whole numbers whenever possible and especially at the beginning of new topics. Many pupils who can visualize a force of twenty pounds see nothing but a number when confronted by the expression 17.32 pounds. For one thing, skill with the latter number is not essential on the secondary school level. For another, the degree of accuracy is rarely justified. The goal should be the development of basic concepts; refinements follow as needed. For example, the individual who

A TYPICAL MATHEMATICS PROGRAM, GRADES 1-8

	Grade 1-3	Grade 4
Number concept:	Develop concepts of small numbers. Learn to count to 1000. Count by 2's, 3's, 4's, 5's and 10's. Read simple Roman numerals. Read and write dollars and cents. Understand labeling of concrete numbers.	Extend concepts of numbers. Read and write to 10,000. Extend use of Roman numerals. Extend understanding of concrete numbers.
Fundamental processes:	Learn addition of three columns, subtraction of three orders, grouping and separating techniques, multiplication by 2's, 3's, 4's, and 5's. Learn checking techniques.	Extend addition and subtraction skills. Extend multiplication and division to all combinations. Learn multiplication by third order, division by one order. Increase checking consciousness.
Fractions, decimals, percentage:	Learn to use simple unit fractions.	Extend concept of unit fractions. Introduce non-unit fractions. Add and subtract fractions having same denominator.
Ratio and proportion, graphs:		
Measurement:	Become familiar with *common units* through use.	Extend familiarity with common units. *Practice* estimation and judging. *Introduce one-step reductions.*
Geometry:	Recognize and describe common *geometric forms* such as wheels, blocks, and balls.	Identify common figures *such as circles, triangles,* and squares.
Algebraic processes:		

Grade 5	Grade 6	Grade 7	Grade 8
Extend concepts of larger numbers.	Read and write through billions. Learn to round off numbers.	Continue to extend and refine number concept.	Continue to extend and refine number concept.
Maintain existing skills. Extend multiplication to all reasonable types. Extend division to third order divisors. Increase checking consciousness.	Continue to refine skills. Give attention to remedial work.	Continue work of grade six.	Continue work of grade seven.
Develop concept of families of fractions. Add, subtract, and multiply simple fractions. Develop decimal concept. Add, subtract, multiply, and divide simple decimals.	Extend skills to operations with all fractions, mixed numbers, and decimals. Interpret percents and hundredths.	Continue to develop basic skills. Learn common percentage equivalents. Extend Case I of percentage. Introduce Case II and apply.	Continue to develop skills. Continue to extend applications of percentage.
Read simple graphs. Read simple scale drawings.	Read and construct simple graphs and scale drawings. Apply ratio concept.	Extend use of graphs. Continue use of scale drawings.	Continue work of grade seven.
Extend use of common units. Continue one step reductions. Calculate fractional parts of units.	Organize tables of measures. Learn to compute with denominate numbers.	Continue use of all operations. Introduce angle measurements.	Continue use of all operations. Introduce metric system.
Study properties of squares and rectangles. Measure perimeters.	Learn to measure areas of rectangles. Recognize characteristics of common figures.	Study properties of plane figures. Learn to make geometric constructions.	Learn to measure areas of irregular figures. Compute volumes of simple solids. Study properties of angles.
		Use formulas for perimeters and areas.	Use basic algebraic processes as aids in problem solving.

knows that a circle is about three times as far around as across has an understanding that he can apply again and again; when he needs greater accuracy it is simple to show him how to attain it.



The so-called "descriptive" sciences can be truly descriptive only if quantity is involved. These biology pupils are weighing dry beans preparatory to an experiment with the imbibition of water. Later they will weigh soaked beans and determine the percentage of increase.

Individual differences in mathematical ability can be provided for by individualizing assignments. During a seventh grade study of electrical energy several pupils were asked to find the cost of operating a 1000-watt iron for three hours. Another group was asked to calculate the cost of leaving a 75-watt lamp lighted each night for a month. Other pupils were given assignments ranging between these extremes in difficulty. Similarly in laboratory work, problems can call for different degrees of skill with numbers.

At the beginning of an exercise with density, the ninth grade science teacher asked for a show of hands of pupils who attained high grades in their mathematics courses. To these pupils he gave blocks that measured in fractional numbers in all three dimensions. To pupils who admitted less skill he gave blocks that measured in even numbers in two dimensions. To the remainder he gave blocks that measured in even numbers in all three dimensions.

The teacher may also ask talented pupils to investigate special phases of an experiment that other pupils are doing. And always, talented pupils can be detached to work on special projects.

Strengthening number concepts. One of the basic aims of the elementary school mathematics program is the development of an apprecia-

tion for the significance of numbers. This aim should be set for the secondary school also. An appreciation for numbers never stops growing. A person always discovers new characteristics of numbers as long as he uses them with understanding.

Small numbers should not be neglected merely because they were emphasized in the early grades. A pupil who discovers that the flowers of a trillium are each composed of three sepals, three petals, a three-parted pistil, and three pairs of stamens, gains a new insight on the characteristics of the numbers three and six. A study of a strawberry blossom gives a concept of radial symmetry as applied to the number five in a way that cannot be gained from study of linear arrangements.

There are many secondary school pupils who benefit by opportunities to arrange pictures on a bulletin board and divide up a number of potted plants among the window sills in the classroom. These experiences help them develop "number sense," without which they later will not be able to keep budgets and balance checkbooks. Sometimes it is not until they reach the secondary school that certain young people are ready for basic concepts. A casual remark by a science teacher that the problem of arranging fourteen pictures in three rows on a bulletin represented a quotient and a remainder opened the eyes of a pupil to the real significance of these terms.

Opportunities for counting are almost endless. Almost every field study and laboratory exercise can involve numbers—experiments with heart rate, determination of strength of magnets, analysis of sand. For specific examples of the possibilities in the study of trees the following activities are described:

1. The age of a tree can be determined with a fair degree of accuracy by counting the rings in a stump or basal log. A permanent record can be made by "rubbings," tacking a strip of paper across the stump and rubbing it with a soft pencil. Causes for unequal growth can sometimes be determined; large scars on one side slow growth on that side; unequal lighting such as is found on a hillside causes faster growth of the well-lighted side; emergence through the canopy formed by other trees gives a forest tree a sudden spurt of growth. Dates for all these events can be determined.

2. The age of young pines and spruces can be determined by counting the spaces between the whorls of branches, since these sections of trunk represent the upward growth for their respective years. An injury to the leader, or main trunk, of one of these trees results in one or more side branches turning upward to assume the function of the leader; this produces crooked or forked trunks. The year of the injury can be determined by counting from the top of the trunk downward.

3. The end of each year's growth of a hardwood twig is marked by a scar around the twig. The scar persists for several years and can be used in dating twigs and saplings. Apple blossoms leave easily identi-

fied scars on their twigs, and it is even possible to distinguish whether fruit were borne and whether some of them grew to full size. Dating these events gives an understanding of the life histories of apple trees.

These three examples show how easily counting exercises are included in a "non-mathematical" course like biology. Usually more than counting is involved; pupils have opportunities to manipulate the numbers as well.

An appreciation for larger numbers can be strengthened by comparisons, by groupings, and other techniques which assist also in giving understandings of the properties of these numbers.

Two girls made a study of the effect of changing the number of turns on an electromagnet, counting the number of brads picked up for each trial. To report their findings they mounted the brads in groups of ten on a chart. Thus their classmates could see at a glance the relationships of the numbers.

A similar technique was seen in a report presented by a pupil who, while dissecting a frog, had discovered it to be full of eggs. She counted out the eggs, one hundred to a vial, and displayed these to illustrate the fecundity of frogs.

Averaging. Pupils have opportunities to practice averaging from about the fourth grade on and have adequate skill with the process. However, about the only practical applications they encounter come when determining grades. In the science program they can be shown how useful averaging is for bringing large masses of data into a form that permits ready comparisons.

Miss Donati led half her class in deep breathing exercises while the other half sat quietly as a control group. She then directed all pupils to stop breathing for as long as possible, each person raising a hand as soon as he took his first breath. Within a short time hands began to fly up, mostly from the control group at first, later by the others.

After a little discussion, the pupils wanted to time themselves. Miss Donati provided a large clock with a sweep second hand and asked them to time themselves She prepared a chart on the blackboard for the data while the pupils carried out the experiment. Afterwards the pupils entered the times in the chart, made a copy for their notebooks, and averaged the two sets of data for comparisons.

Miss Donati could have carried this experiment further. She could have invited comparisons between boys and girls. She could have suggested that the pupils test the effects of changing the amount of preliminary deep breathing. Each new trial would have given more practice with averaging.

Averaging techniques may be used to bring together data to provide a broader base on which conclusions may be drawn.

Early in his chemistry courses Mr. Hawes introduced the experiment on the change in weight of magnesium oxidized in a covered crucible so that his pupils would understand how empirical formulas are derived. During the preliminary discussion of sources of errors, it was obvious that single trials would not be trustworthy. Mr. Hawes proposed that each laboratory team make two trials and pool the data with other members of the class, averaging results to arrive at a single set of values.

Though pupils have little difficulty averaging several quantities as outlined above, they seem to have much more difficulty determining average speeds during intervals of constant acceleration. The situations are enough different so that transfer is difficult. Most pupils will need special help with this phase of averaging.

Percentage. The study of percentages is commonly introduced in the sixth grade and retaught and given greater meaning in the junior high school years. Pupils in the seventh and eighth grades, therefore, will not be adept with the basic processes and will need help before they can use percentages in their science work.

A seventh grade group weighed apples, sliced them in thin strips for drying in an oven, and a day later reweighed them. The pupils assumed that all water was lost in the drying process and calculated the percentage of water in the original apples. Several interested pupils used the same technique for other foods.

There are many problems in biology that call for the use of percentages. The following illustrates one of the many ways in which mathematics can be brought into the life science courses.

Several biology pupils chose to test the viability of seeds for a special project. They prepared a "ragdoll" germination tester—a strip of cloth on which seeds are placed, then rolled up and kept moist for a few days. The percentage of seeds that germinated was calculated for each case.

This project could have been carried further. Pupils could have determined the effects of high temperature, storage at low temperatures, influence of such gases as methane and carbon dioxide, and many other factors.

Similar opportunities may be exploited in the physical sciences.

Mr. Stevens borrowed from a garage a chart listing the number of quarts of antifreeze needed to protect radiators at different temperatures. After

a discussion of antifreeze solutions Mr. Stevens brought out the chart and helped his pupils determine the percentage recommended in each case. Final data was plotted on a graph.

In the earth sciences percentages may be used in experimental work on the composition of soils, water retention in soils, nature of alluvial deposits and the like. The study of slopes represents an entirely different use of percentages and should be treated separately.

Mr. Hunter wished his pupils to use a U.S. Conservation Department bulletin giving soil loss from experimental plots of different slopes. Mr. Hunter took his class outdoors where they measured different slopes and calculated the slopes in terms of percents. For each slope studied the pupils also determined the probable soil loss per acre and the value of this soil at local topsoil rates.

Ratios. Pupils encounter simple ratios early in the elementary grades but have no formal study until the sixth or seventh grades. Secondary school pupils as a whole, therefore, can handle with ease only such simple ratios as 1:3 and such easily reducible ratios as 60:10. Some pupils have not grasped the significance of a ratio written as 6:8. Many cannot reduce such as ratio as 54:153 nor estimate the value of such a ratio as 59:6. Most pupils will need more or less help whenever complex ratios are encountered.

In all phases of the science program pupils have opportunities to use ratios during the preparation of mixtures and solutions. They would gain a great deal if they were allowed to make up many of the stock solutions already prepared for them.

Many projects developed during the study of sound make use of ratios. A xylophone made of sections of broom handle, for instance, may be prepared according to instructions that give the ratios of the respective sections. Pupils may discover the ratios themselves by sliding bridges under a vibrating string until the notes of the standard scale are obtained.

Pupils interested in photography have two opportunities to use ratios. They may mix their own solutions. They may calculate the degrees of enlargement to be used.

Among the commonest uses of ratios in biology is in the work with genetics. Pupils should have opportunities to compute the ratios themselves, instead of being given the "purified" results. They can raise fruit flies, count differently colored kernels in ears of corn, and raise corn seedlings that possess lethal genes.

An interesting application of ratios is found in the study of human growth and development. Among the ratios that pupils may calculate

from actual measurements of children of different ages are: (1) vertical distance between top of head and bridge of nose as compared with vertical distance between bridge of nose to tip of chin; (2) length of head to total length of body; (3) length of arm to body length; (4) length of leg to body length; (5) shoulder width to hip width.

Ratios may be used in studies of plant growth especially in experiments that compare the effects of different factors with a standard set of conditions. These include testing the effects of various fertilizers on the production of plant tissue (dry weight), and the effect of relative humidity on water loss from plants.

In the physical sciences the term "velocity ratio" comes to mind. This is not a happy term because pupils do not calculate velocities but distances in arriving at the velocity ratio. It is much better to speak of the ratio of effort distance to resistance distance. Pupils need to be shown that the ratio may be calculated in different ways for different machines; with levers and pulleys the actual distances are measured, with wheels and axles the radii are measured; with belts the circumferences of the pulleys are usually used, with gears the number of teeth are compared. With wheels and gears the speeds may also be compared. Even angles may be used in some instances.

The pupils in Mr. Welch's physics class jacked up the front end of a car. Then they turned the steering wheel slowly until the front wheels had moved through a 30 degree angle. By measuring the angle through which the steering wheel had turned and comparing it with 30 degrees, they were able to determine the steering ratio of the car.

Measurements. Opportunities for practice in making measurements within the science program need no discussion; they are self-obvious. But a few words might well be said about the capabilities of young people. Pupils are given opportunities to measure time, temperature, short distances and liquids while still in the early grades. Areas and cubic measure, however, are not introduced until the fifth and sixth grades respectively. Angle measurement is usually deferred until the junior high school years.

All pupils can be expected to make simple conversions of common units. Two-step conversions, such as gallons to pints, may give trouble to some pupils, especially when they are dealing with units such as miles, which are difficult to visualize. Fractional parts of units give trouble to pupils who do not have a sound grasp of fractions; indeed there are few pupils who can work with sixteenths of inches. Aside from work with money, which is a special case, pupils have little practice with tenths of units.

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The metric system of measurements is usually presented in the

eighth and ninth years of a general mathematics sequence, but little practice is given. Science teachers should assume that their pupils know nothing about meters, liters and grams. The metric system should be used more in the science program than it is. Seventh graders have no difficulty making measurements in centimeters, meters, grams, kilograms, and milliliters. Confusion does not arise until well-meaning teachers ask them to convert metric measurements to the English system—a skill that has little purpose for most people. Metric system measurements should be treated just as are measurements in inches, pounds and quarts.

Scales and scale drawings. Pupils usually have a brief introduction to the use of scales in the elementary school; they are given increased practice in general mathematics and vocational subjects. They can be expected to interpret simple scale drawings that involve only common units and simple ratios. Their ability to interpret other scale drawings and make their own drawings depends upon each individual's skill with fractions and ratios. Most will need some help in starting a scale drawing which must fit a predetermined space.

Pupils can gain practice in interpreting scale drawings through the making of scale models and scientific apparatus, such as Wardian cases, bacterial colony counters, and plant presses. These are described in professional literature and make good projects for pupils. In earth science pupils may make scale models of topographic features. One teacher asked each pupil to make a cigar-box sized model of some local feature; these made an excellent display and could be stored in cigar boxes when not in use. Many teachers ask pupils to make a model of the solar system; when this is done it should be set up outdoors to the same scale in so far as is practical, so that pupils do not get distorted impressions of sizes and distances.

A general science teacher asked a committee of pupils to make a scale drawing to show relative heights of mountains, depths of oceans, and diameter of the earth. A long sheet of wrapping paper stretched across one end of the room represented a section through the earth. At the ends were drawn some of the highest mountains and greatest ocean depths. This model could have included some of the levels of the atmosphere also.

The above technique can be used for time scales. A biology teacher used a long strip of wrapping paper to represent geologic time. This was divided into eras. Pupils pasted cut-outs of the dominant forms of life in each of the eras.

Maps and mapping. Maps, which are a special form of scale drawing, are usually given adequate consideration in earth science, but rela-

tively few pupils take that course. General science should therefore emphasize maps, and other subjects may use them as well.

Mr. Wilson's biology class undertook an ecological survey of a small area near the school. As a first step the pupils mapped the area, using a plane table constructed according to a design in a scouting magazine. Next, they laid out a line of stakes at equal distances across the area, connecting these with white twine. The line and stake were plotted on the map. The pupils made a census of all plants growing along the line thus obtaining a representative section of the area. Notes were kept on animals seen. The final report of the project was an exhibit of the map, pressed plant specimens keyed to the map, and the list of animals also keyed to the map.

The preparation of a map during the ecological study of an area provides many varied mathematical experiences. These boys are using a plane table in mapping a section of a school lawn.

Pupils like to work with topographic maps of regions familiar to them, probably because of the wealth of detail given. However, they often have trouble interpreting contours. Various techniques for helping them have been employed.

The United States Geological Survey puts out several plastic relief maps, which bear contour lines and are otherwise identical with the flat maps of the same areas. The relief maps may be compared with their corresponding topographic sheets.

A useful device sometimes used is a "hill" of clay or plaster. A scribe

or pencil placed on a block and moved about the hill inscribes a contour line. Another block is added and the scribe is moved about again, producing another contour line. When contour lines have been inscribed to the top of the hill and are viewed from directly above, they resemble a topographic sheet with contours.

A technique like the above, which permits all pupils to participate directly, provides each group of pupils with half a large potato which becomes a "hill." Pupils slice this into layers of equal thickness, which, when reassembled and viewed from above, show the contour lines of the hill. A map may be made by tracing about each layer in turn on a sheet of paper, the layers being put in the respective positions they occupied in the potato.

The preparation of a relief model from data given on a contour map has been described in chapter 14.

Pupils may also survey a limited area and prepare a contour map. The area should have considerable relief to be exciting.

Mr. Schmidt helped his pupils prepare levels for making a contour map. A short board, the sighting bar, was nailed across the top of a five foot stake in the form of a T A small spirit level attached to the sighting bar told them when the latter was horizontal.

To use it, one pupil held the level horizontal while a second pupil sighted along the top. A third pupil would mark the point where the line of sight intersected the ground. This point would be five feet above the point where the level rested.

Mr. Schmidt's pupils marked the points with pieces of white paper, each group of pupils being responsible for one series of points across a hillside. From a distance the lines of papers could be interpreted as contours and were drawn freehand on a map of the area.

Graphs. Pupils have been introduced to all the common forms of graphs in the elementary school. Junior high school pupils can usually interpret them satisfactorily. However, many pupils will need help in constructing graphs, particularly in choosing proper scales. Some will always need help in choosing the proper form to use.

Throughout the science program pupils may use graphs to report the results of their investigations. Typical of the many possible applications are circle graphs to show the materials used by robins in constructing nests, bar graphs to show the quantities of salts soluble in a given quantity of water at various temperatures, and line graphs to show the voltage recovery of a dry cell that has been shorted.

Graphs need not always be on paper. A health teacher had her pupils construct graphs of the composition of foods by painting sections of dowels with different colors, blue for water, red for protein,

and so on. Each dowel represented a different food. These were displayed by inserting them in a base board drilled with shallow holes.

Angle measurement. Pupils do not have practice with angle measurement before the junior high school mathematics program, but they will have little difficulty with this topic if the teacher gives them proper help and chooses his applications wisely.

Investigation of the laws of reflection should utilize angle measurement. Protractors should be a part of the equipment supplied for this purpose. If the pupils have learned to construct angles and erect perpendiculars in their mathematics program they will find satisfaction in using these processes here.

Angles of refraction and critical angles may be demonstrated with a beam of light falling on an aquarium of water clouded with a few drops of milk. The angles may be measured with a large plastic protractor. Needless to say, these phenomena should be given numerous applications to everyday occurrences.

The measurement of angles is important in the study of vision. Pupils may determine the extent of their peripheral vision. The pupil being tested sights across a large square of soft construction board at a pin stuck along the far edge. At the same time he moves a pencil along one side of the board until he can no longer see it. At this point he inserts another pin. He repeats the process for the other side. The extent of his vision is measured in degrees and may be determined for each eye separately and for both eyes together.

Ability to judge size and distance is dependent in part upon subtended angles. Two objects of unequal size at the same distance subtend unequal angles; the mind attributes the larger size to the object subtending the larger angle. Two objects of equal size at different distances subtend unequal angles; the mind attributes the greater distance to the object subtending the smaller angle. When the mind has no basis for judgment, optical illusions may occur—toy-like appearance of buildings from a hill top, apparent change in size of moon as it rises—and these may be explained in terms of subtended angles.

Angles may be measured in a number of experiments with living things. The degree of slope which affects negatively geotropic animals may be determined. The hourly motion of the unsupported tip of a climbing bean seedling may be expressed in degrees. The phototropic shift of leaves and flowers is best expressed in terms of angles.

Angle measurement is important in the study of astronomy. The angle of elevation of the sun at various times of year may be calculated by constructing a triangle based on a vertical stick and its shadow. The hourly shift of the sun and the determination of time

with a sundial utilize angle measurement. Latitude should not be ignored.

Mr. Jordan explained the relationship of latitude and angle of elevation of the North Star. He helped his pupils make simple alidades for the measurement of angles of elevation, and on the next "star study" night meeting, he showed the pupils how to determine latitude.

The basis for vector analysis can be laid in general science, using simple relationships and direct measurements rather than extensive calculations.

Two pupils demonstrated the effect of changing the slope of an inclined board up which they were pulling a loaded roller skate. The slope was increased in 10 degree steps and change in force noted. Results were plotted as a line graph. (The curve approximated the sine curve, but this would not have been significant to the pupils at the time. Later, they might recall it.)

Triangles and other plane figures. Pupils will have become familiar with common polygons by the end of the sixth grade. In junior high school mathematics they study some of the properties of these figures and learn simple geometric constructions. They can employ this knowledge in the science program.

The triangle. Triangles are of special importance in mechanics because they cannot be distorted if the length of their sides remain unchanged. Pupils can compare the rigidity of triangles with that of other polygons by making simple frameworks of heavy cardboard pinned at the corners with paper fasteners. When the lack of rigidity of a rectangle has been discovered, a diagonal brace, which produces two triangles, may be added to discover its effect. Applications are innumerable, from a corner brace on a fence or a guy wire on a pole to complex bridges and skyscrapers.

The special properties of an isosceles triangle may be used in constructing a level. If the bottom member of a framework shaped like an isosceles triangle is level, a plumb bob suspended from the vertex will bisect the base. Addition of a protractor converts this level into an inclinometer which may be used in measuring slopes in various science problems. The same device inverted and suspended on a nail through the midpoint of the base becomes a sighting level for laying out contours; it may need some checking to assure that it is perfectly balanced and gives a horizontal sighting line.

Pupils will be interested to note that living things rarely employ the triangle in their bodies, probably because the triangle cannot be produced by continuous growth processes. The bracing effect of the

triangle is produced, however, by buttress-like tree roots and thickening at the angles where bones meet.

The hexagon. Hexagonal forms are shown in snowflakes, although these can be seen only in certain types of snowfalls, because numerous factors tend to destroy the original form. When conditions are suitable, pupils may collect these snowflakes on dark cloth and study them with hand lenses. The pupils should have opportunities to draw hexagons and attempt to duplicate snowflake patterns around the axes. They may then fold the paper and make cutouts of the patterns.

The circle. A circle is defined as the locus of a point moving at a constant distance from another point. This definition becomes especially evident to pupils who make "star trails" by making time exposures of the night sky centered about the North Star.

The property of a circle that keeps it from changing if its radii do not change is used in the construction of wheels. Formerly all wheels had spokes that would resist compressive forces; these had to be heavy to avoid buckling. More recently it was realized that if spokes could resist only tensile forces the wheel could not change shape and the spokes could be much lighter. The two types of wheels can be demonstrated with rims of cardboard and spokes of dowels and thread respectively.

The ellipse. The term "ellipse" is used commonly in describing the paths of planets but pupils have only a vague understanding of what an ellipse is like. They may construct an ellipse with the aid of two pins and a loop of string as shown in figure 18. They should experiment with the effects of shifting the positions of the pins and changing the length of the loop.

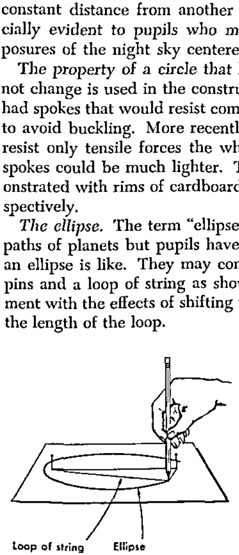

FIGURE 18. *Method of constructing an ellipse with two pins and a loop of string.*

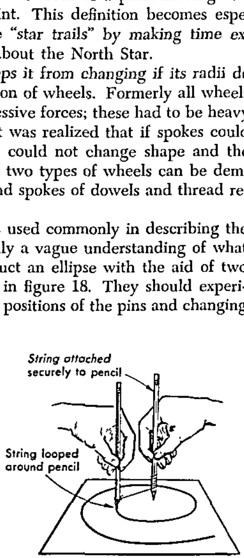

FIGURE 19. *Method of constructing an approximation of the spiral of Archimedes, using two pencils and a piece of string.*

Textbooks tend to distort the elliptical path of the earth's orbit to the point that pupils have confused ideas about the relative distances between earth and sun at different times of year. If pupils try to make a scale drawing of the earth's orbit they will find that the two pins must occupy almost the same point, the ellipse being so near a circle in shape.

The spiral. In the study of phonograph records pupils will encounter the spiral. An approximation of the spiral known as the spiral of Archimedes can be made with two pencils and a piece of string as shown in figure 19; the spiral is not exactly true because the center is constantly shifting around the circumference of the pencil but pupils can grasp the general idea of a uniformly changing radius. Spirals will also be found in reels of film and tape.

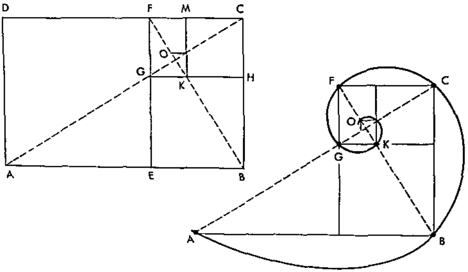

FIGURE 20. *A logarithmic spiral. To construct geometrically the approximation of a logarithmic spiral, construct a rectangle ABCD, with sides having the ratio 1.618:1. Divide the rectangle into a square AEFD and its reciprocal rectangle EBCF. Divide the latter into a square and its reciprocal rectangle. Continue to divide the reciprocal rectangles thus formed in the same fashion. The points ABCFGK. . . . . lie on a logarithmic spiral.*

If the radius of the curve changes at an ever increasing rate, a logarithmic spiral may be produced. This curve, often found in living things, such as the shells of snails, the heads of sunflowers, and the cones of pine trees, is formed as the power of growth increases with the size of the organism. Pupils in biology classes may approximate this curve by the constructions shown in figure 20, without knowledge of algebra.

The catenary. Few people notice that the cables of a suspension bridge have a very special curve known as the catenary. This is the curve assumed naturally by a heavy, flexible cable supported at the ends. In the catenary, the resultant forces along the cable, caused by the weight of the cable, are reduced to the least possible value. When used for a suspension bridge, the weight of the roadway and vehicles is transferred to the cable by numerous vertical strands, each of such a length that the catenary is not distorted. In effect, these merely add to the weight of the cable and forces in the cable are kept at a minimum.

Pupils may construct the catenary by stretching a soft, well-worn clothesline or rope across a blackboard and tracing the curve with chalk. If they draw a horizontal line beneath and connect it to the curve with vertical lines they will have a representation of a suspension bridge.

The arch. Arches illustrate another application of curves to mechanics. Circular and parabolic arches are most commonly used, the latter being the stronger. Where beauty is more important than strength other types are used. Pupils may experiment with the arch to determine its characteristics. A band of thin steel, such as is used for binding large cartons, will support a relatively small load when laid across two supports. But curved upwards and buttressed at the ends, it will support a far greater load without distortion. Pupils may also make arches of blocks of plaster of Paris to see how masonry arches operate. Arches are encountered in nature. Shells of turtles, snails and clams are types of arches. A clam shell will withstand a considerable force when stepped on but snaps readily when bent with pliers.

Triangulation. As soon as pupils are introduced to trigonometry in ninth grade mathematics they can be helped to apply it in general science. Many questions which arise about determination of distance in astronomy can now be answered.

Even without knowledge of the trigonometric functions, pupils can be shown applications of triangulation from two points. They may make maps using plane tables, by setting up a table at first one end and then the other of a measured base line and taking a series of "fixes" on different objects. The point where the lines of sight intersect on the map is marked as the location of each object. Such maps are useful in ecological studies. Applications of the same principles can be found in the location of forest fires by fire-tower observers, in navigation at sea and in geographic surveys.

An interesting application is seen in the field of radiology. The problem in treating internal cancers is to provide radiation of sufficient

intensity to kill the cancer cells without damaging surrounding tissues. Two sources of radiation may be used, neither powerful enough to damage tissue but each beamed at the cancerous tissue. Where the beams intersect, the intensity of radiation is sufficient to kill the cancer cells.

Three-dimensional figures. Pupils are given brief experiences with such common solids as cylinders and cubes in the junior high school mathematics program, but their knowledge of the properties is not extensive. They can learn much more through the study of common applications.

The cylinder. Pupils will have noticed without questioning the extensive use of cylindrical containers for liquids and compressed gases. They can be shown that for a given amount of material the cylindrical container has the greatest capacity—barring the spherical container which is difficult to construct—and is easiest of all to construct. Even more important, however, is the strength of this type of container. Outward thrusts are converted into tensile forces around the walls, forces which thin metal can withstand best without distortion. Outward thrust on the walls of a rectangular container produce a bending force which thin metal cannot well resist, and the walls bulge. Enormous forces are simultaneously exerted on the corners of the container. The stability of a cylindrical container can be demonstrated by filling a canvas water bucket with water; it then becomes rigid and maintains its shape because of the uniform distribution of tensile forces in the canvas.

The special properties of hollow cylinders, used so extensively in construction, have many applications in biology.

Miss Starkweather directed each pupil to roll a sheet of notebook paper into a hollow cylinder and secure it with plastic tape. She then asked the pupils to find out how many books their tubes would bear in an upright position. Pupils were amazed at the loads.

Miss Starkweather pointed out that for a given amount of material the greatest strength is provided by incorporating it into a hollow cylinder. She applied the principle to the stems of quick growing plants such as bamboo, and illustrated her point with a length of bamboo and a cylinder of wood of equal weight. She asked her pupils to look for similar examples and bring in for study the stems of such plants as corn, hollyhocks, cow parsnip, and goldenrod.

The hexagon. The hexagonal containers built by honey bees should certainly be studied when the insects are studied. Bits of honey comb

may be examined and the structure of the cells noted. Making drawings helps to point out the special characteristics most effectively. Pupils will quickly realize that only hexagons and squares permit such close grouping. Then a little simple mathematics will show that the hexagonal form uses less wax than the square.

Crystals. Natural crystals exist in a bewildering variety of shapes. Study is further complicated by distortions and tendencies for intergrowth. Orderly thinking about crystals is promoted by the study of models.

Beautiful models can be constructed by joining sheets of clear plastic with transparent cement or transparent tape. Axes are indicated by lengths of colored thread passed through holes in the plastic and cemented in place. Crystals may be carved more easily and this carving can be made part of a laboratory exercise in earth science. The pupils begin with cubes of potato or plaster of Paris. By truncating the corners they produce a duodecahedron. Continued truncation produces other forms.

The helix. Of all the many other figures, only the curve known as the helix will be mentioned here. The helix is extensively used in coiled springs. When a load is applied to a coiled spring, a twisting torque is applied along the length of the rod making up the spring. Steel distorts readily under a twisting torque and permits the coil to lengthen or shorten, depending upon the way the load is applied. Thus the high elasticity of steel can be utilized to lessen shocks in a way that would be impractical otherwise.

Some plants, notably the grape vine, use the same principle in their tendrils. The tendrils "give" as the wind blows and then pull the vine back in place.

Leaf arrangement on twigs have a helical pattern. It is very evident in the arrangement of the needles on spruce twigs. It can be seen on hardwood twigs by tying a thread to one leaf base and passing it from leaf base to leaf base up the twig. Even on a potato, which is a modified stem, the helical arrangement can be shown by inserting toothpicks in the "eyes" and passing a thread from toothpick to toothpick.

The helical pattern of leaf arrangement varies with species, and the pattern is described in terms of "divergencies." A twig with opposite leaves is said to have a divergency of $\frac{1}{2}$ because a line drawn from leaf base to the next above (around the twig) would go only half way around the twig. The divergency would be $\frac{1}{3}$ if the line went one-third of the way around. Known divergencies follow the series $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, and so on. Note the relationships of the numerators and denominators; the sum of two successive terms equals the next.

ture measurements. Pupils are required to write both values, one in parentheses. Thus they automatically gain an idea of the relationship. The outcome is certainly worth the added cost.

Pupils will always discover the conversion formulas but these should not be taught deliberately. They have value only to the specialist who makes frequent conversions. They are learned with difficulty and forgotten with ease. Pupils should be shown how to draw two scales side by side with freezing and boiling points coinciding, and work out any needed conversions directly. This they can never forget if they know both systems to start with.

Formulas and equations. Science teachers commonly complain that their pupils do not know algebra. Sometimes this is true, pupils who elect only general mathematics have so little work with equations that their experience can be discounted. However, pupils who elect elementary algebra can deal with most of the linear equations that are developed in any realistic physics problems. Those who elect intermediate algebra can handle most of the quadratic equations that arise. What teachers mean, when they complain of pupils' abilities, is that their pupils do not know how to apply algebraic processes to the situations they encounter in science. It is the science teacher's responsibility to help them make these applications.

It is to be feared that science teachers do not always understand the mathematics they employ, or if they do they are so eager for results they take short cuts without proper explanations.

"I don't see how you can multiply pounds times inches," said a ninth grade girl during work with levers.

"Well, you can!" snapped her teacher. "See! I just did it."

This teacher's tart remark amused the class, embarrassed the girl, and exposed his own ignorance. Multiplication, as a form of repeated additions, permits no such hybrid joinings. But science teachers employ them constantly in "solving" problems.

Formulas, as the most used mathematical devices, are also the most abused. Too often pupils are required to memorize the formulas, apply them mechanically, and work out solutions blindly, even improperly, as was just described. The pupils are thus able to give a show of competence, but their competence is a thin shell that bears no weight.

Whenever possible, formulas should be developed inductively from data which the pupils collect themselves, organize to discover relationships, and express in their own ways. The pupils then know that the formula is but a short way of expressing a relationship and they

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